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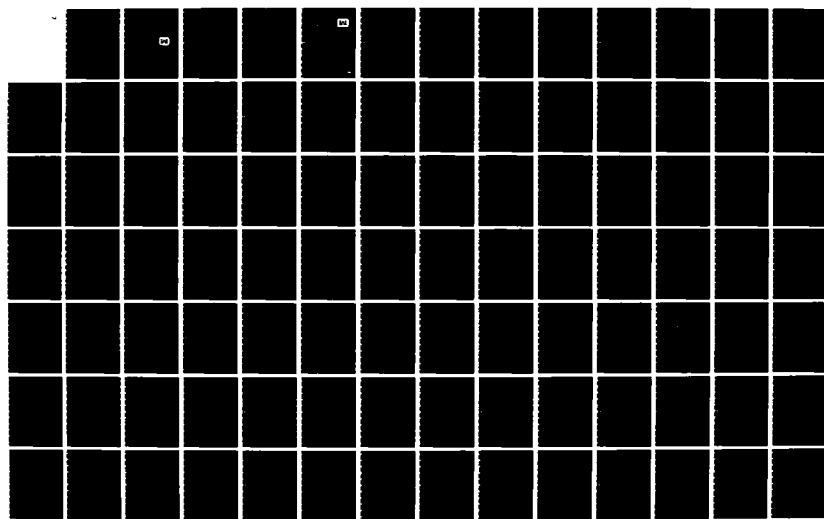
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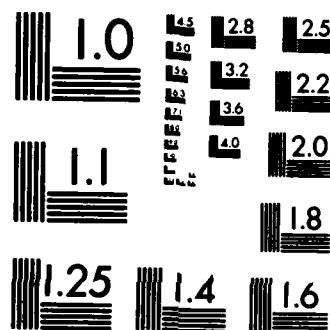
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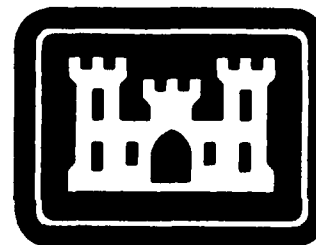


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OPERATION, MAINTENANCE  
AND PERFORMANCE EVALUATION

of the

POTOMAC ESTUARY EXPERIMENTAL  
WATER TREATMENT PLANT

MAIN VOLUME

SEPTEMBER 1980 - SEPTEMBER 1983

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Water Resources Act of 1974 authorized the Baltimore District of the U.S. Army Corps of Engineers to investigate the use of the Potomac River Estuary as a possible supplemental water supply source for the Metropolitan Washington Area (MWA). Use of the Estuary, a source expected to be contaminated with substantial amounts of treated wastewater during a severe drought, was one of several structural and non-structural alternatives to meet the long term water supply needs of the MWA, which were evaluated in the U.S. Army Corps of Engineers' MWA Water		

## 19. KEY WORDS (continued)

Estuary Model.

## 20. ABSTRACT (continued)

Supply Study.

The investigation evaluated the water quality produced by a 1.0 MGD demonstration water treatment plant (EEWTP), which was located adjacent to the Estuary at the Blue Plains WPCP, Washington, D. C.

Based on certain hydrologic conditions and the results of the EPA Dynamic Estuary Model, a raw water mix of 50 percent estuary water and 50 percent nitrified Blue Plains sewage effluent was selected for treatment.

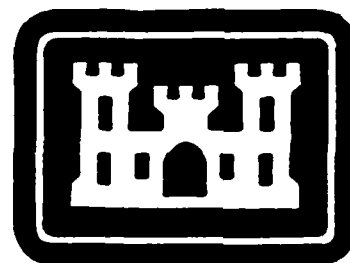
Three water treatment process combinations were investigated. The first process combination included alum coagulation, sedimentation, intermediate chlorination, gravity filtration, granular activated carbon (GAC) adsorption and free chlorine disinfection. The second process substituted ozone as the intermediate oxidant. The final combination consisted of lime coagulation, sedimentation, recarbonation, gravity filtration, GAC adsorption at twice the contact time, ozone and chloramine for final disinfection.

An extensive water quality analysis program was conducted to determine the acceptability of the water for human consumption. The sampling frequency rates exceeded recommended standards. The analytical program parameters included physical and aesthetical (13); major cations, anions and nutrients (19); trace metals (24); radiological (5); microbiological (6) including enteric viruses (41 identifiable types), parasites (7), and four bacterial groups; organic (151); and toxicological (2). Finished water samples were collected from three MWA water treatment plants to compare their water quality against the project's finished water quality.

Within the limits of the analytical techniques used and the influent water quality conditions observed it was concluded that the three process combinations monitored were technically feasible of producing a water acceptable for human consumption.

Estimated treatment cost for a 200 MGD estuary water treatment plant, using design and operating criteria similar to that used in the EEWTP, are approximately 34.3¢/1000 gallons for the first alum mode and 47.6¢/1000 gallons for the lime mode of operations. Due to uncertainties over the plant's location, intake and certain finished water structures and related costs were excluded from the cost estimates.

**U.S. ARMY  
CORPS OF ENGINEERS  
BALTIMORE DISTRICT**



**OPERATION, MAINTENANCE  
AND PERFORMANCE EVALUATION  
of the  
POTOMAC ESTUARY EXPERIMENTAL  
WATER TREATMENT PLANT**

**MAIN VOLUME**

**SEPTEMBER 1980 - SEPTEMBER 1983**

**JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.**



## ACKNOWLEDGEMENTS

The Potomac Estuary Experimental Water Treatment Plant project was conducted under the supervision and direction of the U.S. Army Corps of Engineers, Baltimore District.

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## LIST OF ABBREVIATIONS

In order to conserve space and improve readability, the following abbreviations have been used in this report:

A	area
ACS	automatic composite sampler
BNA	base/neutral acid extraction
BOD <sub>5</sub>	5-day biochemical oxygen demand
cm	centimeter
CLS	closed-loop stripping
°C	degrees centigrade
D.C.	District of Columbia
DEM	Dynamic Estuary Model
D.L	detection limit
D.T.	detention time
ECD	electron capture detector
EEWTP	Estuary Experimental Water Treatment Plant
EPA	Environmental Protection Agency
ERL	Environmental Research Laboratory
eV	electron volt
FID	flame ionization detector
ft	feet
g	grams
G	mixing energy
GAC	granular activated carbon
GC	gas chromatograph
gpd	gallons per day
gpm	gallons per minute
HERL	Health Effects Research Lab
hp	horsepower
HP	Hewlett Packard
HPLC	high performance liquid chromatography
HSDM	Homogenous Surface Diffusion Model
IC	Ion Chromatograph

## List of Abbreviations

ICAP	inductively coupled argon plasma
ID	inside diameter
JAWWA	Journal of the American Water Works Association
JMM	James M. Montgomery, Consulting Engineers, Inc.
JWPCF	Journal of the Water Pollution Control Federation
KV	kilovolts
M	moles/liter
MBAS	Methylene-Blue Active Substances
$\mu\text{m}$	micrometers
$\mu\text{g/L}$	microgram/liter
$\mu\text{l}$	microliters
$\mu\text{mho}$	micromho
MDC	minimal detectable concentration
MDL	minimum detection limit
MF	membrane filter
MFL	million fibers per liter
MGD	million gallons per day
$\text{mg/L}$	milligram/liter
MINC	Modular Instrument Computer
mm	millimeter
mM	millimole/liter
MPI	Malcolm Pirnie, Inc.
MPN	most probable number
MS	mass spectrometer
mw	molecular weight
MWA	Metropolitan Washington Area
N	normal concentration
NAS/NAE	National Academy of Science/National Academy of Engineers
nm	nanometer
NRC	National Research Council
NTU	nephelometric turbidity unit
ODCS	Operator Data Collection System
P/A	precision/accuracy
PDF	probability density function
PM	preventive maintenance

## List of Abbreviations

ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
Q	volumetric flow
QA	quality assurance
QC	quality control
rpm	revolutions per minute
RWQTP	Routine Water Quality Testing Program
sec	seconds
SIMS	Sample Information and Management System
SOCs	synthetic organic chemicals
SPC	standard plate count
TAC	technical advisory committee
TDS	total dissolved solids
THM	trihalomethanes
TTHM	total trihalomethanes
TOC	total organic carbon
TON	total organic nitrogen
TOX	total organic halide
TPPAM	Testing Program for Process Adjustment and Modification
TSS	total suspended solids
UV	ultra violet (light)
VAX	Virtual Access Extension
VOA	volatile organic analyses
wt	weight
WQ	water quality
yr	year



## **CHAPTER 1**

### **PROJECT DESCRIPTION**

This chapter presents the background for the initiation of the Potomac Estuary Experimental Water Treatment Plant (EEWTP) project and reviews the project objectives and scope. The facilities at the EEWTP are described. Finally, the criteria used for evaluating finished water quality are presented and the approach used to determine technical feasibility is discussed.

## **SECTION 1**

### **BACKGROUND**

The Potomac Estuary Experimental Water Treatment Plant (EEWTP) project was authorized by Section 85(b)(2) of the Water Resources Development Act of 1974 (Public Law 93-251, 7 March 1974) which directs that:

"The Secretary of the Army, acting through the Chief of Engineers, shall undertake an investigation and study of the use of estuary waters to determine the feasibility of using such waters as a source of water supply and is authorized to construct, operate, and evaluate a pilot project on the Potomac estuary for the treatment of such waters at an estimated cost of \$6,000,000. The Secretary of the Army, acting through the Chief of Engineers, shall report to the Congress on the results of such project within three years after commencement of operation of such project and such report shall include the results of two years testing at the pilot project for the treatment of water from the Potomac Estuary."

Further, Section 85(b)(1) of the Act directs that a thorough investigation be made of the existing and future water supply needs of the MWA and that recommendations be made to the U.S. Congress for satisfying such needs. This study, known as the Metropolitan Washington Area Water Supply Study (MWAWS), was done by the Baltimore District of the Corps of Engineers and will be submitted to Congress in September 1983.

In addition, Section 85(b)(3) directs the Secretary of the Army to request the National Academy of Sciences-National Academy of Engineering (NAS-NAE) to review and provide written comment on the scientific basis for conclusions reached in both the MWA Water Supply Study and the EEWTP testing program.

Furthermore, the NAS-NAE Committee was requested to provide project review on a regular basis throughout the duration of the project beginning with the conceptual stage and continuing through the performance evaluation of the EEWTP. The Committee met approximately every six to eight months for review of conceptual design of the treatment processes, development of the testing program for monitoring of the EEWTP, and finally for review of progress reports submitted as part of the operation, maintenance, and performance evaluation of the EEWTP.

The NAS-NAE Committee played an important role in determining the technical direction of the project. Comments were prepared for the U.S. Army Corps of Engineers in the form of letter reports. Additional advice was provided by the Panel on Water Quality Reuse, a joint panel between the National Research Council (NRC) Academy of Life Sciences, Safe Drinking Water Committee funded by EPA and the Committee to Review the Potomac

## Background

Estuary Experimental Wastewater Treatment Plant. Review meetings provided useful exchange between the NAS-NAE Committee and the U.S. Army Corps of Engineers on all aspects of the project.

The history of water resources development in the Potomac River Basin includes many Congressional authorizations for individual studies, projects, and planning reports (see e.g., U.S. Army Corps of Engineers, 1963 to 1979). These studies will be reviewed in detail in the MWA Water Supply Study.

This report presents the results of the two years of monitoring of the EEWTP and the principal conclusions regarding the technical feasibility of using the estuary as a water supply source. The costs of water treatment processes for producing a water acceptable for human consumption, are summarized. These costs can be used to compare an estuary water treatment plant with other proposed alternatives discussed in the MWA Water Supply Study for meeting the long term water supply needs of the MWA.

## **SECTION 2**

### **PROJECT OBJECTIVES**

#### **OBJECTIVE**

The objective of the Potomac Estuary Experimental Water Treatment Plant (EEWTP) project was to demonstrate the technical feasibility of using the tidal fresh portion of the Potomac River estuary as a supplemental water supply source for the Metropolitan Washington Area (MWA).

In this context technical feasibility has been defined as a demonstration that water of acceptable quality for human consumption can be produced by a selected combination of readily available unit processes and operations common to current water treatment technology. The capital and annual costs can be estimated and used as a basis for comparing this alternative to other alternatives proposed for meeting the long-term water supply needs of the MWA.

#### **SPECIFIC OBJECTIVES**

To achieve the project objective answers were needed for a series of specific questions. These questions, listed below, formed the basis for the scope of work developed for the operation, maintenance and performance evaluation of the EEWTP.

1. What influent water quality to the EEWTP best simulates projected conditions in the Potomac River estuary under drought conditions?

Under drought conditions equivalent to the droughts of 1930-1931 and 1965-1966, the Potomac River estuary is anticipated to contain a high percentage of treated wastewater. To simulate the water quality conditions that might be encountered by a future regional estuarine water treatment plant, the EEWTP was located close to the Blue Plains Wastewater Treatment Plant and the Potomac River estuary. Selection of the appropriate mix from these two sources to serve as the blended influent to the EEWTP was an essential first step in reaching the objective of the project.

2. What quality of water can be produced by commonly used water treatment processes?

The National Interim Primary Drinking Water Regulations (NIPDWR) are based on a community water system utilizing the best economically available source. It is generally assumed that the source will be subjected to a minimum of contamination by pollution sources. Intentional use of a contaminated source is not addressed by current standards. In such cases,

## Project Objectives

the finished water could meet all primary drinking water regulations and still not be of acceptable quality for human consumption. Under these conditions, it was necessary to monitor a greater number of water quality parameters with a frequency greater than that required by the NIPDWR. It was also important to select a sampling procedure which would provide a statistically reliable characterization of critical water quality parameters. Specific project objectives were to select the appropriate water quality parameters, the appropriate frequency of sampling and the type of samples that should be collected, based on an initial monitoring program developed prior to operation of the demonstration plant.

3. Is the EEWTP finished water of acceptable quality for human consumption?

Use of the Potomac River estuary as a supplemental water source for the Metropolitan Washington Area (MWA) is a controversial strategy because the estuary is an unprotected water source subject to significant treated wastewater discharges and untreated urban runoff. During a drought, some fraction of the raw water source would consist of treated wastewater. This would constitute a case of indirect reuse or the unplanned recycle of treated wastewater.

Currently, there is considerable disagreement among water supply authorities on the appropriate treatment requirements for producing a water acceptable for human consumption when the raw water source is contaminated. Some authorities also question the suitability of the current drinking water regulations for evaluating the acceptability of a treated or finished water under these conditions. In a recent symposium on the subject of reuse for potable purposes (EPA, December 1982), opinions differed on whether or not a judgement could even be made on the acceptability for human consumption of a finished water drawn from a contaminated source because of current limitations in analytical techniques, toxicological testing, and risk estimation.

It is well known, for example, that detection and quantitation of organic chemicals present in drinking waters are possible for only a small fraction, on the order of ten percent, of the organic chemicals constituting the dissolved organic carbon in water. Similarly, current microbiological techniques can detect only a small number of the microorganisms in water, and for certain microbiological contaminants, for example, viruses, the high cost of the analyses restricts the frequency with which the test can be conducted.

The National Research Council has recently addressed the issue of quality criteria for potable use regardless of the source water quality (NRC, 1983). In their view, technical feasibility must be evaluated on the basis of extensive toxicological testing of the finished water.

The extensive toxicological testing recommended by NRC was considered for this study. However, the protocols of the suggested toxicological tests are not fully developed, nor can the results of such

## Project Objectives

tests be translated into risk estimation. Furthermore, toxicological testing is expensive, and budget constraints, even in a project of this magnitude, did not permit more than a limited number of such tests. Therefore, it was not possible in this project to conduct all the toxicological tests recommended by the NRC. Instead, as recommended by the NRC, a comparative approach was used as the principal basis for determining technical feasibility.

It was postulated that if the quality of the finished water produced by any selected process combination at the EEWTP compared favorably with the finished water quality from one or more of the major water treatment plants in the MWA, then the EEWTP finished water may be acceptable for human consumption.

4. What are the process combinations which will ensure a finished water of acceptable quality?

The EEWTP consisted of a number of water treatment process options in order to provide flexibility in operation. Most of these processes represent treatment technologies that are commonly used in water treatment plants in the U.S. A specific project objective was to select those process combinations deemed feasible for producing a water of acceptable quality, given the estimated quality of the blended influent.

5. What is an acceptable level of reliability for the selected process combination?

The water quality in the Potomac River estuary exhibits considerable variability. Even under drought conditions, it is expected that fluctuations would occur in the levels of numerous parameters due to storm events. Consequently, the selected process combination should be tested over a sufficient length of time to ensure confidence in the mechanical and process reliability of the processes tested. The observed mechanical reliability of the process will determine the extent to which redundant processes are required. The observed process reliability will provide an estimate of the probability that the selected process combination would meet drinking water regulations, or other specific water goals based on the water quality observed in the local supplies.

6. What are the estimated costs of the selected processes for treating the water to a defined level of quality?

Based on resolution of the previous questions, a final specific objective was to determine the capital and annual costs associated with the process combination or combinations demonstrated to produce water of acceptable quality for human consumption.

## **Project Objectives**

### **PROJECT DURATION**

Design of the EEWTP was initiated in 1974 and completed in 1976 by Malcolm Pirnie, Inc. Construction of the EEWTP was completed in 1980. James M. Montgomery, Consulting Engineers, Inc. conducted the operation, maintenance, and performance evaluation of the EEWTP under the technical direction of the U.S. Army Corps of Engineers, Washington Aqueduct Division (WAD). The operation, maintenance and performance evaluation of the EEWTP was scheduled for a three-year duration. The project consisted of six months of plant start-up, two years of plant operation and six months of plant deactivation and preparation of the final report.

## SECTION 3

### SITE DESCRIPTION

#### PROJECT LOCATION

The EEWTP was located in the southern section of Washington, D.C. opposite Alexandria, Virginia and below the confluence of the Anacostia and Potomac Rivers (see Figure 1.3-1). The specific site location of the EEWTP is shown in Figure 1.3-2. The plant was located on the northern edge of the Blue Plains Wastewater Treatment Plant close to the Potomac River estuary to permit withdrawal of influent water from two sites. Use of this land was provided by the District of Columbia, Department of Environmental Services, through an agreement with the Corps of Engineers.

The Blue Plains Wastewater Treatment Plant is a regional sewage treatment facility handling wastewaters originating in the District of Columbia and several of the surrounding counties in Maryland and Virginia. The treatment plant handles flows originating from an area of approximately 725 square miles including both separate and combined sewer systems. The wastewater is principally domestic in nature. The Blue Plains plant is the major discharger in the MWA and is capable of treating approximately 309 MGD. Effluent discharge criteria require that the treatment plant provide phosphorus removal (achieved by chemical precipitation) and nitrification. Final treatment includes filtration and disinfection with chlorine.

One source of water for the EEWTP was the unfiltered, nitrified effluent from the Blue Plains Plant.

The other source for the EEWTP was the Potomac River estuary. An intake line and pumping station provided delivery of up to 1 MGD of water from the estuary. This portion of the estuary is designated as a tidal fresh zone indicating that under normal hydrological conditions, the levels of total dissolved solids (TDS) do not exceed that of the background TDS in the river.

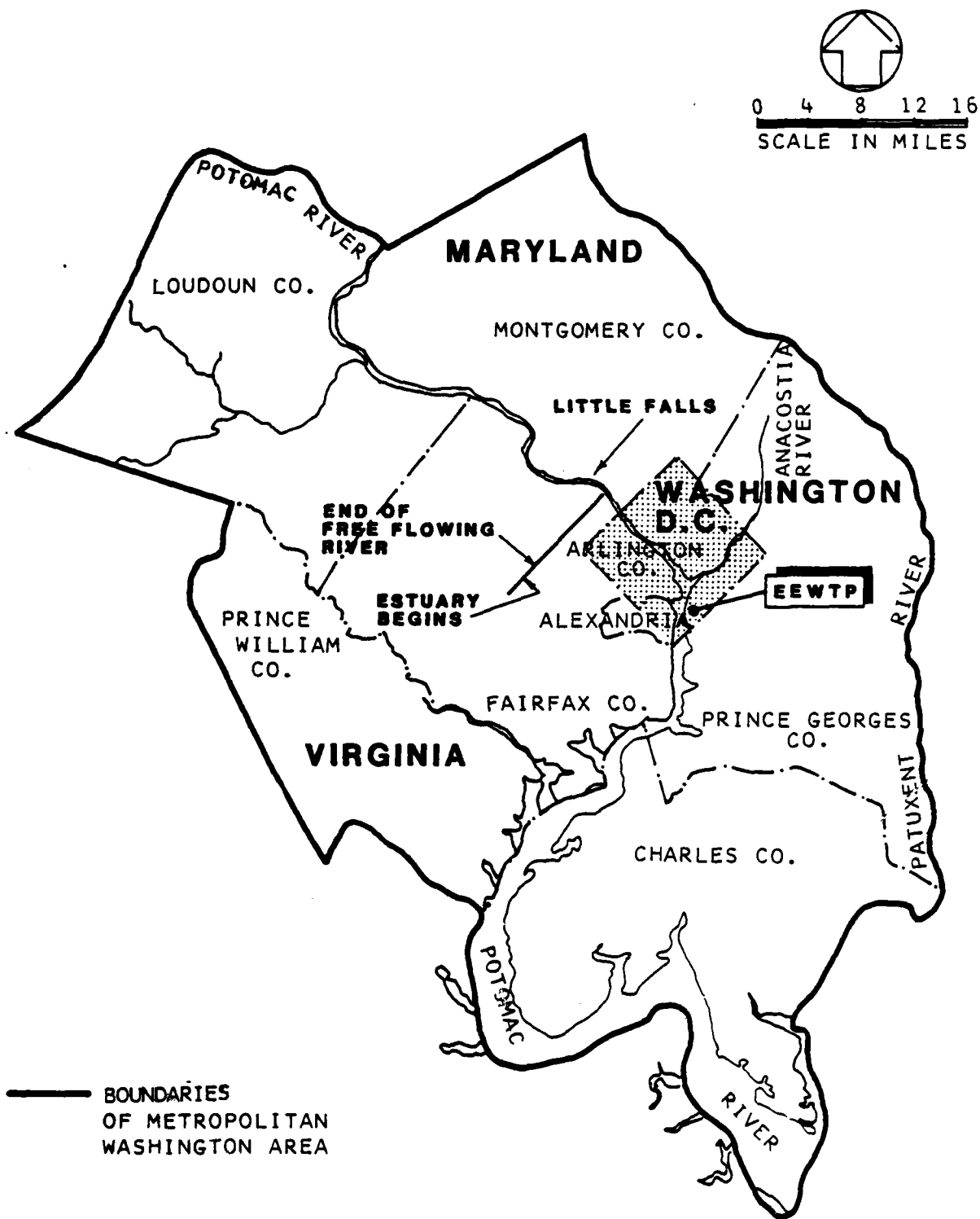
#### PROJECT FACILITIES

The EEWTP was designed with a 1 MGD maximum hydraulic capacity which was considered necessary to demonstrate the feasibility of using the Potomac River estuary under conditions which simulate actual operation of a full-scale water treatment plant.

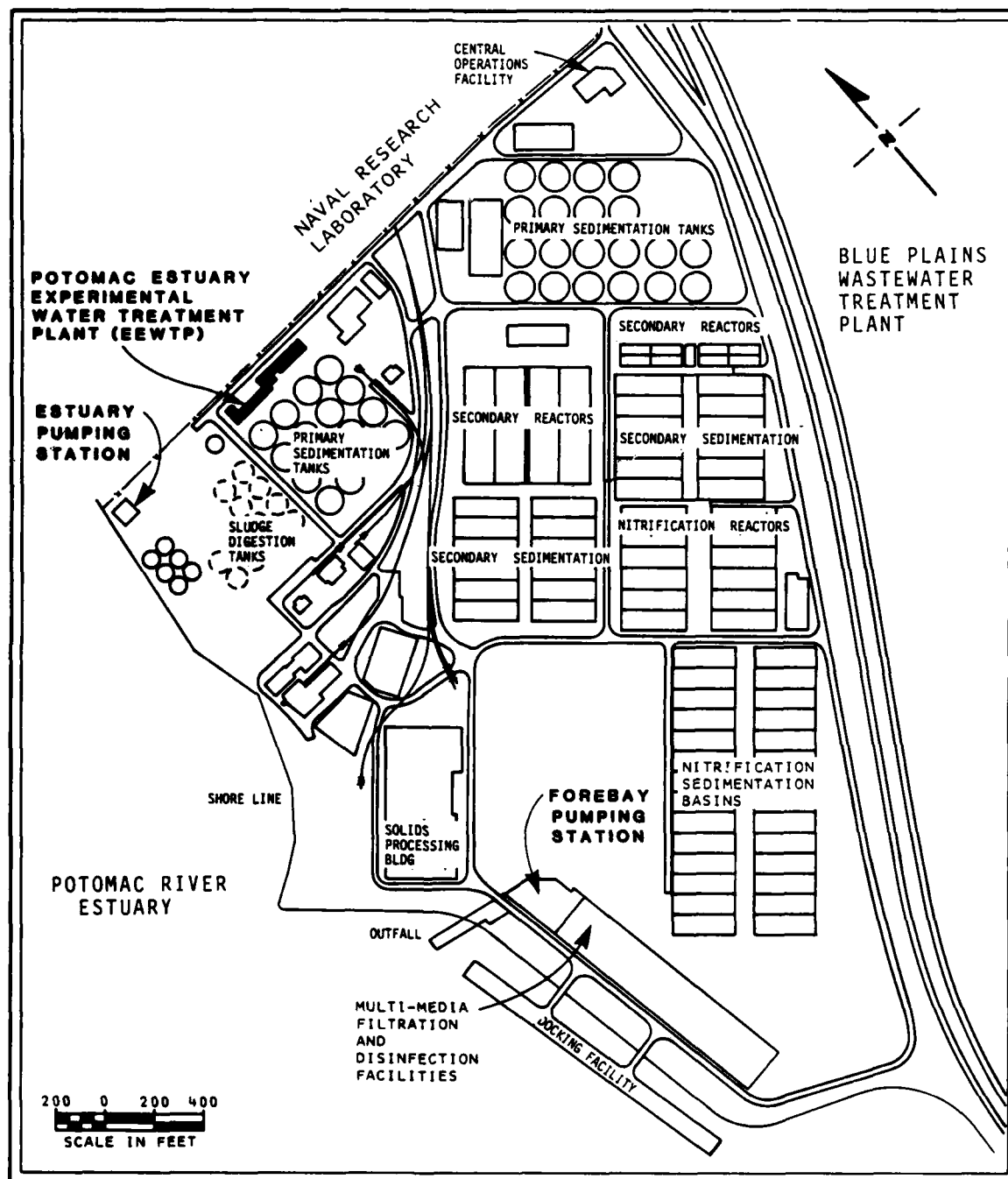
#### LIQUID PROCESSING FACILITIES

The treatment plant was designed with a variety of unit processes which are representative of existing technology in the water treatment field. The available processes and their principal treatment objectives are summarized in





**PROJECT LOCATION MAP**  
**FIGURE 1. 3-1**



**SITE PLAN FOR THE POTOMAC ESTUARY  
EXPERIMENTAL WATER TREATMENT PLANT  
FIGURE 1. 3-2**

## Site Description

Table 1.3-1. The principal process options available included use of aluminum sulfate (alum) or calcium oxide (lime) as coagulants, the application of either chlorine or ozone as an intermediate oxidant and disinfectant, the use of granular activated carbon (GAC) for the control of organic compounds, and the use of either ozone, chlorine, chloramines, or a combination of these as the final disinfectant(s). In addition, removal of dissolved inorganic contaminants could be achieved with the reverse osmosis process.

### SOLIDS PROCESSING

In the operation of a water treatment plant, solids are removed from the coagulation, sedimentation and filtration processes and treated for disposal. The EEWTP was provided with facilities for sludge thickening, and sludge disposal to the Blue Plains Wastewater Treatment Plant. In addition, coagulant recovery facilities were provided to evaluate recovery of either lime or alum coagulants.

Due to time and funding constraints the sludge recovery facilities were not operated during the course of the study. Sufficient published information is currently available to determine if coagulant recovery facilities would be a technically feasible and cost effective alternative for solids handling should an estuary water treatment plant be built. Demonstration of coagulant recovery was not considered to be a significant factor regarding the feasibility of using the estuary as a drinking water source.

## Site Description

TABLE 1.3-1  
LIQUID PROCESSING SYSTEMS  
ESTUARY EXPERIMENTAL WATER TREATMENT PLANT

<u>Unit Process</u>	<u>Process Objective</u>
Microscreens	Removal of relatively large particulate matter and associated contaminants (e.g., trace metals, viruses).
Mechanical Aeration	Oxidation of manganese and iron; partial removal of volatile organic compounds or objectionable dissolved gases (e.g., hydrogen sulfide).
Chemical Addition/Flocculation	Colloidal destabilization, formation of flocculant solids.
Sedimentation	Removal by gravity settling of suspended particulates and flocculated particles including some adsorbed and entrapped contaminants (i.e., heavy metals, dissolved organics, viruses).
Intermediate Disinfection (ozone or chlorine)	Initial destruction of pathogenic organisms and control of bacteriological growth in the filters; oxidation of manganese
Filtration	Removal of residual suspended and colloidal material and associated contaminants by retention on granular media.
Activated Carbon Adsorption	Removal of dissolved organic contaminants.
Reverse Osmosis	Removal of dissolved inorganic contaminants, and some dissolved organics.
Final Disinfection	Destruction of pathogenic microorganisms.

## SECTION 4

### SCOPE OF REPORT

This report consists of an executive summary, a main volume, and ten appendices. The executive summary provides a synopsis of the project approach, methods, and conclusions. The main volume contains support documentation for the principal findings. Additional documentation on analytical methods, data management, plant operations, special studies, and statistical summaries of monitoring results are included in the appendices.

Chapter 1 presents an overview of the project, a description of the EEWTP, and a discussion of the criteria for evaluating the quality of water produced by the EEWTP.

Chapter 2 presents the project conclusions.

Chapter 3 reviews the monitoring programs instituted to characterize water quality, and to evaluate the performance of the water treatment processes used in the EEWTP. Sampling sites, sample frequency, sample handling, and water quality parameters monitored are discussed. Revisions to the monitoring program are presented which were based on statistical analyses of the water quality data generated during the first several months of the monitoring program.

Chapter 4 provides an overview of analytical methods utilized in the testing program. Sampling handling protocols, precision and accuracy data, detection limits, and quality control programs are also summarized. Detailed analytical protocols are included in Appendix A.

Chapter 5 presents an overview of the statistical techniques used to characterize the data from the monitoring programs. The significance of statistics used to characterize the data is discussed. Procedures used for comparison of finished water quality between the EEWTP and the three off-site treatment plants are presented. Details of the statistical techniques are provided in Appendix B.

Chapter 6 presents the modeling results for projection of water quality in the Potomac River estuary under drought conditions, based on the use of the Dynamic Estuary Model (DEM). Details of the DEM are described in Appendix C. The impacts of several hydrologic scenarios on projected water quality are discussed as characterized principally by total dissolved solids and other conservative inorganic parameters. Water quality data from the monitoring of the two influents, Blue Plains nitrified effluent and Potomac River estuary, are presented. The water quality of the blended influent is compared to the DEM predictions to evaluate the accuracy of the selected influent blend in matching

## Scope of Report

model projections. Summaries of all monitoring results for the influent waters are provided in Appendix F.

Chapters 7 and 8 contain the results of the plant monitoring program for the alum and lime operational phases, respectively. The basis for selection of the process combinations used in the EEWTP is presented along with the description of design and operation criteria for individual processes monitored. Overall performance and the fate of individual parameters through the treatment sequence are discussed. In addition, the process performance of each major unit process is analyzed with respect to key water quality parameters. Results of process performance monitoring are given in Appendix G. Design criteria for the EEWTP are shown in Appendix D. Additional process data are presented in Appendix E.

Chapter 9 presents the evaluation of finished water quality for the operational phases tested. The EEWTP finished water quality is compared to Maximum Contaminant Levels (MCLs) in the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations. For all parameters with potential health or aesthetic concerns, a comparison is made between the EEWTP finished water quality and the finished water quality of the three local major water treatment plants in the MWA. In cases where the EEWTP finished water quality exhibits higher levels than the local plants, but still meets current standards, comparisons are made with available water quality data from other sources including results of national surveys of U.S. water treatment plant performance. Statistical summaries of the data for monitoring of the finished waters are presented in Appendix H. Results of a special organic monitoring program are shown in Appendix J.

Chapter 10 contains a summary of the engineering studies and process analyses completed during the project. Detailed presentations of each study are included in Appendix I. These include studies of alternative processes which could not be evaluated in the EEWTP, including the use of air stripping for control of volatile organic chemicals, alternative designs of granular activated carbon, and reverse osmosis for removal of dissolved inorganic contaminants.

Chapter 11 summarizes process alternatives and costs. This final chapter presents the cost estimates for those process combinations shown to be capable of producing a water of acceptable quality for human consumption. Cost estimates are shown for a hypothetical estuary treatment plant located at an undetermined site on the estuary. Estimates are based on the cost of the treatment plant only, at a capacity level of 200 MGD using design and operational criteria tested during the two-year monitoring program. Finally, the cost and water quality implications of process combinations or alternative operational criteria which could not be monitored in the EEWTP are discussed.

## **SECTION 5**

### **CRITERIA FOR EVALUATING WATER QUALITY**

#### **BACKGROUND**

The principle objective of the project was to determine the technical feasibility of using the tidal fresh portion of the Potomac River estuary as a supplemental water supply source for the Metropolitan Washington Area (MWA). In this determination, a major issue was the acceptability for human consumption of the finished water produced by the EEWTP. This evaluation required a definition of acceptable water quality, a difficult task in the context of treating a contaminated surface source and, in particular, a situation where treated wastewaters may constitute a substantial fraction of the source.

For those water quality parameters which can be quantified with current analytical techniques, the evaluation of EEWTP finished water quality can be based on one or more of the following comparisons:

1. Comparison of the level of a water quality parameter in the EEWTP finished water to existing Federal or State drinking water regulations.
2. Comparison of EEWTP finished water quality to the quality of conventional supplies in the MWA.
3. Comparison of levels of water quality parameters in EEWTP finished water to potential Federal or state regulations, to standards proposed for treating waters to potable quality regardless of the source, or to specific levels of parameters estimated to pose health risks.
4. Comparison of levels of water quality parameters in EEWTP finished waters to levels of particular parameters found in community water systems treating unprotected sources, that is, those systems treating a source substantially influenced by treated wastewater discharges.

This section presents an overview of each of these criteria, and its limitations for determining the suitability of the EEWTP finished water for human consumption.

#### **COMPARISON TO DRINKING WATER REGULATIONS**

##### **NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS**

The National Interim Primary Drinking Water Regulations (NIPDWR) were promulgated by EPA in 1975 (EPA, 1975; EPA, 1980c), thus fulfilling the mandate of the Safe Drinking Water Act of 1974. These standards were based on the assumption that a community water system would utilize the water source of the highest quality economically available. The Act stated explicitly that "polluted sources should not be used unless other sources are economically unavailable, and then only when personnel, equipment and operating procedures

## Criteria for Evaluating Water Quality

can be depended on to purify and otherwise continuously protect the drinking water supply." (EPA, 1976).

The NIPDWR specified Maximum Contaminant Levels (MCLs) for selected microbiological, physical/aesthetic, inorganic, radiological and organic parameters. These MCLs were selected for those parameters believed to have adverse impacts on health, either chronic or acute and are summarized in Table 1.5-1.

TABLE 1.5-1  
MAXIMUM CONTAMINANT LEVELS  
NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

<u>Parameter</u>	<u>Units</u>	<u>Value</u>
Microbiological <sup>1</sup>		
Coliform Bacteria	MPN/100 ml	1
Physical/Aesthetic		
Turbidity	NTU	1
Major Cations, Anions and Nutrients		
Nitrate, NO <sub>3</sub> -N	mg/L	10
Fluoride, F <sup>2-</sup>	mg/L	1.4 - 2.4
Trace Metals		
Arsenic, As	mg/L	0.05
Barium, Ba	mg/L	1
Cadmium, Cd	mg/L	0.010
Chromium, Cr	mg/L	0.05
Lead, Pb	mg/L	0.05
Mercury, Hg	mg/L	0.002
Selenium, Se	mg/L	0.01
Silver, Ag	mg/L	0.05
Radiological		
Radium - 226 + Radium -228	pCi/L	5
Gross Alpha Particle Activity	pCi/L	15
Tritium	pCi/L	20,000
Strontium-90	pCi/L	8
Trace Organics		
Endrin	mg/L	0.0002
Gamma-BHC (Lindane)	mg/L	0.004
Methoxychlor	mg/L	0.1
Toxaphene	mg/L	0.005
2,4-D	mg/L	0.1
2,4,5-TP Silvex	mg/L	0.01
Total Trihalomethanes (TTHMs)	mg/L	0.10

1. MCL depends on technique and sampling frequency; see regulations.

2. Level of F depends on annual average of the maximum daily air temperature.



## Criteria for Evaluating Water Quality

The NIPDWR also include monitoring requirements for sodium (Na). Because of the possible adverse health impact of Na on persons suffering from hypertension, the NIPDWR recommends that the Na levels not exceed 20 mg/L. This is not an MCL however. In addition to numerical standards, the NIPDWR specified acceptable sampling frequencies for each parameter. For example, the turbidity standard is based on a monthly average utilizing daily grab samples as the basis for the average. On the other hand the standard for trihalomethanes is based on a twelve month running average based on a sample frequency of not less than once every three months. Thus, a community water system may exceed the value of MCL on occasions, but must operate in a manner that ensures that the average concentration, as determined from the defined sampling frequency, remains below the MCL.

In the context of the EEWTP project, these MCLs served as target levels not to be exceeded. All parameters were monitored more frequently than required by the NIPDWR, and values exceeding the MCLs were anticipated. For these cases, the final evaluation of the acceptability of the EEWTP finished water quality was based on comparison with the quality of water produced by the local water treatment plants in the MWA as discussed below.

### NATIONAL SECONDARY DRINKING WATER REGULATIONS

While the primary regulations are based on health concerns, the secondary regulations address consumer acceptance of the finished water. The MCLs set for the parameters in the secondary regulations are considered to be feasible goals, and as such, are suggested as guidance to the states. They are not, however, federally enforceable in contrast to the MCLs in the NIPDWR. Secondary maximum contaminate levels (SMCLs) became effective on 19 January 1981 (See EPA, 1979a) and are shown in Table 1.5-2.

### COMPARISON TO WATER QUALITY FROM CONVENTIONAL SUPPLIES

Because of uncertainties associated with the use of the NIPRWR for evaluating the potability of water obtained from a contaminated source, meeting the primary or secondary regulations may not be sufficient evidence of whether a finished water obtained from such a source is acceptable for human consumption. Consequently, for all parameters in the drinking water regulations, the concentrations observed in the finished water from the EEWTP were also compared to concentrations observed in the finished waters from the three major local water treatment plants in the Metropolitan Washington Area.

### PARAMETERS NOT INCLUDED IN CURRENT (1983) STANDARDS

The primary and secondary regulations omit a number of water quality parameters of potential health significance frequently found in treated wastewaters. Parameters have been omitted because of a lack of monitoring data, inability of current analytical techniques to quantify the parameters, excessive monitoring costs, or uncertainty as to the health implications of the parameters. For use of heavily contaminated sources, therefore, additional parameters which may pose health risks to the consumer should be included in any monitoring program. Parameters of particular significance, not included in the National Drinking Water Regulations, are shown in Table 1.5-3.

# Criteria for Evaluating Water Quality

TABLE 1.5-2

## MAXIMUM CONTAMINANT LEVELS NATIONAL SECONDARY DRINKING WATER REGULATIONS

<u>Parameter</u>	<u>Units</u>	<u>Value</u>
Physical/Aesthetic		
pH		6.5 - 8.5
Color (color units)	color units (CU)	15
Odor	threshold odor number, (TON)	3
Foaming agents (methylene blue active substances, MBAS)	mg/L	0.5
Major Cations, Anions, Nutrients		
Chloride	mg/L	250
Sulfate	mg/L	250
Total dissolved solids	mg/L	500
Trace Metals		
Copper (Cu)	mg/L	1
Iron (Fe)	mg/L	0.3
Manganese (Mn)	mg/L	0.05
Zinc (Zn)	mg/L	5
Other		
Corrosivity		Non-corrosive

TABLE 1.5-3

## PARAMETERS OF POTENTIAL HEALTH SIGNIFICANCE NOT INCLUDED IN THE NATIONAL DRINKING WATER REGULATIONS

Microbiological  
     Viruses  
     Parasites  
     Pathogenic bacteria  
 Physical/Aesthetic  
     Asbestos  
 Trace Metals  
     Antimony  
     Beryllium  
     Thallium  
     Nickel  
     Tin  
 Major Cations, Anions  
     Hardness  
     Cyanide  
 Trace Organics  
     Total organic halide (TOX)  
     Synthetic organic chemicals not currently regulated

## Criteria for Evaluating Water Quality

Additional microbiological parameters with potential health effects include viruses, parasites and pathogenic bacteria. These parameters have been found frequently in treated wastewaters, and consequently, monitoring would be required to verify that a treatment sequence could effectively reduce their levels to acceptable limits. One physical/aesthetic parameter not included in the drinking water regulations is asbestos. Asbestos in drinking water may pose potential health risks because of known health effects on humans due to inhalation of air-borne asbestos fibers. This parameter should be included in the monitoring program to determine whether the EEWTP can produce a finished water of acceptable quality for human consumption.

A number of metals not currently regulated have been included in the EPA Priority Pollutant List (EPA, 1979) including, antimony, beryllium, thallium, nickel and tin. While it is unlikely that these particular parameters represent a health risk in water (NAS, 1980), they should be monitored.

Other parameters of potential concern are hardness (potential impact on cardiovascular disease) and cyanide.

A particular area of concern in treating highly contaminated sources is the level of trace organics found in the finished waters. Currently, the primary standards include only four pesticides, two herbicides and the trihalomethanes as shown in Table 1.5-1. Of potential health significance, however, are those synthetic organic chemicals (SOCs) not currently included in the regulations. In this context, SOCs include those produced by industrial activity as well as those produced in the treatment facility by disinfection or oxidation processes used at a water treatment plant. Finally, total organic halide, a parameter measuring the level of volatile and non-volatile halogenated organic compounds, is a parameter which may be an indication of potential health risks to the consumer.

Table 1.5-4 lists the volatile synthetic organic chemicals (VOCs) currently being considered for regulation by the EPA (EPA, 1982). While it is unlikely that maximum contaminant levels will be promulgated for all compounds shown, at least six (TCE, PCE, carbon tetrachloride, 1,1,1-trichloroethane, 1,2-dichloroethane, and vinyl chloride) are expected to be proposed for regulation by EPA in 1983. Proposed MCLs for these compounds range from 1 to 1,000 µg/L.

In addition, the EPA will be required to specify recommended MCLs (RMCLs) for these compounds. The RMCLs are defined as the concentration of the particular parameters which will cause no known adverse health effects.

## Criteria for Evaluating Water Quality

TABLE 1.5-4  
VOLATILE SYNTHETIC ORGANIC CHEMICALS  
CONSIDERED FOR REGULATION

Trichloroethylene (TCE)  
Tetrachloroethylene (PCE)  
Carbon Tetrachloride  
1,1,1-Trichloroethane  
1,2-Dichloroethane  
Vinyl Chloride  
Methylene Chloride  
Benzene  
Chlorobenzene  
Dichlorobenzene  
Trichlorobenzene  
1,1-Dichloroethylene  
Cis and Trans-1,2-dichloroethylene

### RISK ESTIMATES FOR CHEMICALS IN DRINKING WATER

For those parameters not currently included in the drinking water regulations, but which pose potential health risks to consumers, federal agencies have developed risk estimates based on the principles for risk assessment outlined in Drinking Water and Health (National Academy of Sciences, 1977). Estimates of the risk levels for specified concentrations of parameters in drinking water have been made for both non-carcinogens, suspected carcinogens and carcinogens.

#### Non-Carcinogens

For organics which are not carcinogens, acceptable daily intakes and suggested no-adverse-effect levels have been estimated by NAS (1977) using the concept of approximate safety factors, depending on the level of confidence in the toxicity data. Estimates generated for some of the organic chemicals monitored in this project are shown in Table 1.5-5.

Another set of water quality criteria for non-carcinogens in water has been proposed by EPA, Office of Water Planning and Standards (EPA, 1979, e,f,g). Levels shown in Table 1.5-6 represent estimates of concentrations at which exposure to a single chemical is not anticipated to produce adverse effects in man. Both these and the NAS estimates assume an average water consumption of 2 liters per day, for a 70 kg human adult over a life span of seventy years.

# Criteria for Evaluating Water Quality

TABLE 1.5-5

## NO EFFECT LEVELS FOR SELECTED ORGANIC NON-CARCINOGENS MONITORED IN THE EEWTP

Compound	Maximum Dose Producing No Adverse Effect mg/kg/day	Uncertainty Factor <sup>1</sup>	ADI <sup>2</sup> mg/kg/day	Suggested No- Adverse-Effect Level from H <sub>2</sub> O, µg/liter Assumption <sup>3</sup>	
				1	2
2,4-D	12.5	1,000	0.0125	87.5	4.4
2,4,5-T	10.0	100	0.1	700	35.0
TCDD (Dioxin)	10 <sup>-5</sup>	100	10 <sup>-7</sup>	7x10 <sup>-4</sup>	3.5x10 <sup>-5</sup>
2,4,5-TP	0.75	1,000	0.00075	5.25	0.26
Atrazine	21.5	1,000	0.0215	150	7.5
Ci-n-butyl phthalate	110	1,000	0.11	770	38.5
Pentachlorophenol	3	1,000	0.003	21	1.05

1. Uncertainty factor: the factor of 10 was used where good chronic human exposure data were available and supported by chronic oral toxicity data in other species; the factor of 100 was used where good chronic oral toxicity data were available in some animal species; and the factor 1,000 was used with limited chronic toxicity data.
2. Acceptable Daily Intake (ADI): Maximum dose producing no observed adverse effect, divided by the uncertainty factor.
3. Assumptions:
  - Average weight of human adult = 70 kg.
  - Average daily intake of water = 2 L.
  - Column 1: 20% of total ADI assignment to water; 80% from other sources.
  - Column 2: 1% of total ADI assigned to water; 99% from other sources.

# Criteria for Evaluating Water Quality

TABLE 1.5-6  
ESTIMATES FOR NON-CARCINOGENS

Parameter	Maximum Exposure Level for Human Health Protection (µg/L)
<b>INORGANIC CHEMICALS</b>	
Antimony	145
Cyanide	200
Mercury	0.2
Thallium	4
Zinc	5,000
<b>ORGANIC CHEMICALS</b>	
Acenaphthene	20
Acrolein	6.5
Chlorinated Napthalenes	
Trichloronapthalenes	3.9
Tetrachloronapthalenes	1.5
Pentachloronapthalenes	0.39
Hexachloronapthalenes	0.15
Octochloronapthalenes	0.08
Chlorinated Phenols	
2-chlorophenol	0.3
3-chlorophenol	50
4-chlorophenol	30
2,4-dichlorophenol	0.5
2,5-dichlorophenol	3.0
2,6-dichlorophenol	3.0
2,4,5-trichlorophenol	10
2,4,6-trichlorophenol	100
2,3,4,6-tetrachlorophenol	263
Chlorinated Benzenes	
Monochlorobenzene	20
1,2,4-Trichlorobenzene	13
1,2,3,5-Tetrachlorobenzene	17
1,2,4,5-Tetrachlorobenzene	17
Pentachlorobenzene	5
Dichlorobenzene	
1,2-dichlorobenzene	230
1,3-dichlorobenzene	230
1,4-dichloropropane	230
Dichloropropanes	
1,1-dichloropropane	200
1,2-dichloropropane	200
1,3-dichloropropane	200
1,3-dichloropropenes	0.63

## Criteria for Evaluating Water Quality

TABLE 1.5-6 (Continued)  
ESTIMATES FOR NON-CARCINOGENS

Parameter	Maximum Exposure Level for Human Health Protection (µg/L)
Endosulfan	100
Endrin	1
Ethylbenzene	1,100
Fluoranthene	200
Hexachlorocyclopentadiene	1
Isophorone	460
Napthalene	143
Nitrobenzene	30
2,4-dinitrophenol	68.8
Pentachlorophenol	140
Phenol	3,400
Phthalate Esters	
dimethy	160,000
diethy	60,000
dibuty	5,000
di-2-ethylhexyl	10,000
Toluene	17,400

Source (EPA 1979 e,f,g)

### Carcinogens

For organic carcinogens in water, risk estimates have been made by both the NAS and the EPA. Several points are common in each estimate:

1. An average water consumption of two liters per day is assumed.
2. Estimates are based on a lifetime exposure of the contaminants and assume a seventy year life for a 70 kg person.
3. Incremental lifetime cancer risks are calculated for organic chemical concentrations in water. These are estimated risks over and above all other cancer risks faced by an individual. Since approximately twenty percent of all deaths in the United States are from malignancies, this background risk (200,000 per 1,000,000 over a lifetime) is several orders of magnitude higher than the incremental risks typically associated with organic concentrations in drinking water, which cover a wide range but are typically on the order of 1 per 1,000,000.

Risk estimates for organic carcinogens in water prepared by the National Academy of Sciences (NAS, 1977) are summarized in Table 1.5-7. For example,

## Criteria for Evaluating Water Quality

carbon tetrachloride is estimated to produce an incremental or extra lifetime cancer risk of one in a million ( $10^{-6}$ ) if the concentration in water is 4.5  $\mu\text{g/L}$  and a 70 kg person consumes two liters per day of the water for seventy years. Another interpretation of this same number is that one person in a population of one million would develop cancer during a lifetime who would not have developed cancer otherwise.

TABLE 1.5-7  
RISK LEVELS FOR SELECTED ORGANIC CARCINOGENS  
IN DRINKING WATER

Compound	Concentration ( $\mu\text{g/L}$ ) for Estimated Increase in Lifetime Cancer Risks <sup>1</sup>		
	10 <sup>-4</sup>	10 <sup>-5</sup>	10 <sup>-6</sup>
<b>Human Carcinogen</b>			
Vinyl Chloride	100	10	1
Benzene	I.D. <sup>2</sup>	—	—
Acrylonitrile	I.D.	—	—
Bis-chloromethyl ether	I.D.	—	—
<b>Animal Carcinogens</b>			
Trichloroethylene (TCE)	450	45	4.5
Tetrachloroethylene (PCE)	350	35	3.5
Carbon tetrachloride	450	45	4.5
1,2-Dichloroethane	70	7	0.7
Chloroform	30	3	0.3
Arochlor 1260	16	1.6	0.16
Dieldrin	0.19	0.019	0.0019
Aldrin	I.D.	—	—
Kepone	1.1	0.11	0.011
Heptachlor	1.2	0.12	0.012
Chlordane	2.8	0.28	0.028
DDT	4.2	0.42	0.042
Gamma-BHC (Lindane)	12	1.2	0.12

1. Based on NAS Drinking Water and Health (1977). Estimates are for known or suspected organic chemical carcinogens found in drinking water. Assumes two liters per day water intake, seventy year exposure. Calculated from upper 95% confidence estimate of lifetime cancer risk per  $\mu\text{g/L}$ .
2. I.D. = insufficient data to permit a statistical extrapolation of risk.

Additional risk estimates have been made by EPA's Office of Water Planning and Standards (EPA Water Quality Criteria, 1979 e,f,g) for a number of compounds included in the list of priority pollutants; see Table 1.5-8.



## Criteria for Evaluating Water Quality

TABLE 1.5-8  
PRIORITY POLLUTANTS AS SPECIFIED BY EPA  
(EPA, 1979)

### Halogenated methanes (1 carbon)

Methyl bromide  
Methyl chloride  
Dichloromethane (methylene chloride)  
Tribromomethane (bromoform)  
Trichloromethane (chloroform)  
Bromodichloromethane  
Dibromochloromethane  
Dichlorodifluoromethane  
Tetrachloromethane (carbon tetrachloride)

### Chlorinated (2 carbon)

Chloroethane (ethyl chloride)  
Chloroethylene (vinyl chloride)  
1,2-Dichloroethane (ethylene dichloride)  
1,1-Dichloroethane  
1,2-trans-Dichloroethylene  
1,1-Dichloroethylene (vinylidene chloride)  
1,1,2-Trichloroethane  
1,1-Trichloroethane (methyl chloroform)  
Trichloroethylene  
Tetrachloroethylene  
1,1,2,2-Tetrachloroethane  
Hexachloroethane

### Chlorinated (3 carbon)

1,2-Dichloropropane  
1,3-Dichloropropylene

### Chlorinated (4 carbon)

Hexachlorobutadiene

### Chlorinated (5 carbon)

Hexachlorocyclopentadiene

### Chloroalkyl ethers

Bis(chloromethyl)ether  
Bis(2-chloroethyl)ether  
Bis-(2-chloroisopropyl)ether  
2-Chloroethylvinyl ether  
Bis(2-chloroethoxy)methane

## Criteria for Evaluating Water Quality

TABLE 1.5-8 (Continued)  
PRIORITY POLLUTANTS AS SPECIFIED BY EPA  
(EPA, 1979)

### Pesticides

Aldrin  
Dieldrin  
Chlordane  
Alpha-Endosulfan  
Endrin  
Endrin aldehyde  
Heptachlor  
Heptachlor epoxide  
Alpha-BHC  
Beta-BHC  
Delta-BHC  
Gamma-BHC (lindane)  
4,4'-DDT  
4,4'-DDE (p, p'-DDX)  
4,4'-DDD (p, p'-TDE)  
Toxaphene  
TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin)  
(a contaminant of 2,4,5-T)

### Nitrosamines

N-Nitrosodimethylamine  
N-Nitrosodiphenylamine  
N-Nitrosodi-n-propylamine

### Miscellaneous

Acrolein  
Acrylonitrile  
Isophorone  
Cyanide

### Aromatics

Benzene  
Toluene  
Ethyl benzene

### Polyaromatics

Napthalene  
Acenaphthene  
Acenaphthylene  
Anthracene  
Benzo(a)anthracene (1,2-benzathracene)  
Benzo(a)pyrene (3,4-benzopyrene)  
3,4-Benzofluoranthene  
Benzo(k)fluoranthene (11,12-benzofluoranthene)  
Benzo(ghi)-perylene (1,12-benzoperylene)  
Chrysene

## Criteria for Evaluating Water Quality

TABLE 1.5-8 (Continued)  
PRIORITY POLLUTANTS AS SPECIFIED BY EPA  
(EPA, 1979)

Dibenzo(a,h)anthracene(1,2,5,6-dibenz-  
anthracene)  
Fluorene  
Fluoranthene  
Indeno(1,2,3-cd)pyrene(2,3-o-phenylene-  
pyrene)  
Phenanthrene  
Pyrene

### Chloroaromatics

Chlorobenzene  
o-Dichlorobenzene  
p-Dichlorobenzene  
m-Dichlorobenzene  
1,2,4-Trichlorobenzene  
Hexachlorobenzene

### Chlorinated polyaromatic 2-Chloronaphthalene

### Polychlorinated biphenyls

Arochlor 1016  
Arochlor 1221  
Arochlor 1232  
Arochlor 1242  
Arochlor 1248  
Arochlor 1254  
Arochlor 1260

### Phthalate esters

Bis(2-ethylhexyl)phthalate  
Butylbenzyl phthalate  
Di-n-butyl phthalate  
Di-n-octyl phthalate  
Diethyl phthalate  
Dimethyl phthalate

### Nitroaromatics

Nitrobenzene  
2,4-Dinitrotoluene  
2,6-Dinitrotoluene

### Benzidines

Benzidine  
3,3'-Dichlorobenzidine  
1,2-Diphenylhydrazine

## Criteria for Evaluating Water Quality

TABLE 1.5-8 (Continued)  
PRIORITY POLLUTANTS AS SPECIFIED BY EPA  
(EPA, 1979)

### Phenols

Phenol  
2,4-Dimethylphenol

### Nitrophenols

2-Nitrophenol  
4-Nitrophenol  
2,4-Dinitrophenol  
4,6-Dinitro-o-cresol

### Chlorophenols

2-Chlorophenol  
4-Chloro-m-cresol  
2,4-Dichlorophenol  
2,4,6-Trichlorophenol  
Pentachlorophenol

### Haloaryl ethers

4-Chlorophenylphenyl ether  
4-Bromophenylphenyl ether

### Metals

Antimony  
Arsenic  
Beryllium  
Cadmium  
Chromium  
Copper  
Lead  
Mercury  
Nickel  
Selenium  
Silver  
Thallium  
Zinc

## Criteria for Evaluating Water Quality

Where appropriate, incremental lifetime cancer risk levels can be used to provide additional context for evaluating the EEWTP finished water quality for organic or inorganic compounds included in this list, most of which are not included in any current drinking water regulations.

### WATER QUALITY GOALS - REGARDLESS OF SOURCE

Two recent publications by the EPA and the National Research Council (NRC) address the issue of criteria and standards for potable water treatment regardless of the quality of the source (EPA, 1982; National Research Council, 1982). In general, both reports make a number of qualitative recommendations regarding the operation and monitoring of treatment plants treating heavily contaminated sources including 100 percent wastewater (direct reuse). These include the following:

1. The treatment process sequence should include a number of processes (multiple barrier approach) capable of providing satisfactory removal for the individual parameter.
2. The treatment plant should be operated at constant flow to minimize process disruptions and poor quality.
3. Operation of the facility will require higher levels of monitoring and control, higher levels of operator capabilities and capabilities for diversion of the finished water if quality deteriorates.
4. Prior to implementation of such a treatment facility, comparative testing between the finished water from the proposed facility and finished water from conventional water treatment plants is desirable.
5. More extensive monitoring with respect to parameters and frequency of measurements will be required than are specified in the current drinking water regulations.

With respect to individual parameters and specific goals for these parameters, both reports are reluctant to recommend specific numbers. For microbiological contaminants, however, the NRC publication has indicated the desired performance levels of the treatment process. For total coliforms, the ninety percentile value should be less than 0.1/100 ml, with the ninety-eight percentile less than 1/100 ml. For viruses, an MCL of 1 plaque forming unit (pfu)/1000 liters is recommended. In addition, it is recommended that the standard plate count never exceed 100 colonies/ml.

No specific levels were recommended for organic contaminants. However, it was suggested that all organic contaminants be identified and quantified when they occur at levels greater than 1 ug/L. As a minimum, the priority pollutants (see Table 1.5-8) should be monitored. In addition monitoring of surrogate parameters for organic compounds are recommended including total organic carbon (TOC) and total organic halide (TOX).

## Criteria for Evaluating Water Quality

### CRITERIA AND STANDARDS UTILIZED WORLD-WIDE

Use of contaminated water sources is of particular interest in several countries currently approaching the limit of utilization of their surface water supplies. For example, available water supplies are expected to exceed demand by the year 2000 in South Africa (Hart, 1977). Contamination of surface waters and use of such contaminated sources for drinking water is common. Consequently, South Africa has developed lower hazard limits for a number of organics found in drinking waters, listed in Table 1.5-9. Where appropriate these lower hazard limits can be utilized for a quantitative evaluation of finished water quality for selected organic compounds.

TABLE 1.5-9  
LOWER HAZARD LIMITS USED IN SOUTH AFRICA  
FOR SELECTED ORGANIC COMPOUNDS

Organic Compound Groups	Lower Hazard Limits (ug/L)	
	Compound	Group
Volatile halogenated hydrocarbons (VHH)	1-10	50
Trihalomethanes (chloroform, bromoform, bromodichloromethane, dibromochloromethane) carbon tetrachloride		
Chlorinated hydrocarbons/pesticides (CHP)		1
Lindane, chlordane, dieldrin, endrin, (bis)-chloroisopropylether, hexachloroobutadiene, hexachlorobenzene, PCBs, DDT-complex, endosulfan	0.1	
Dichlorobenzene, chloroethers	1	
Chlorophenols (CPHEN)		
Di-, tri-, tetra- and pentachlorophenols	1	10
Polynuclear aromatic hydrocarbons (PAH)		
Benzo(a)anthracene, benzo(b) and (k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene	0.1	
Phenolic compounds (PEHN)		
Phenol, cresols, xlenols, beta-naphthol, etc	1	10
Other compounds (DIV)		
Dibutylphthalate, diphenylether, nitrotoluene	1	
Unidentified compounds to be identified by GC-MS	1	
CHP and PAH	0.1	

## Criteria for Evaluating Water Quality

### COMPARISON OF FINISHED WATER QUALITY WITH WATER FROM UNPROTECTED SOURCES

Although the National Interim Primary Drinking Water Regulations specify that the MCLs are to be utilized only for those sources of the highest quality economically available, such standards are routinely used for evaluation of the quality of water produced by conventional treatment from unprotected sources. Such sources are subjected to various point and non-point discharges of treated wastewaters.

In some cases, it may be appropriate to compare the EEWTP finished water quality to that produced by one or more plants currently utilizing contaminated sources. The extent of indirect reuse worldwide is larger than might be expected and is summarized below.

In 1973 the National Water Commission (EPA, August 1979) stated that indirect reuse is wide-spread in the United States. The Commission estimated that approximately one out of every five gallons drawn for municipal water supply had been previously discharged by an upstream wastewater treatment plant. This level of indirect reuse seems high for a national average, however.

A recent study prepared for EPA (SCS, 1978) indicated that, based on annual average flows for cities using surface sources and serving greater than 25,000 customers, the percentage of treated wastewater in the surface source water ranged between zero and sixteen percent. Under low flow or drought conditions, however, the proportion of treated wastewaters in some cases increased to 100 percent of the flow.

Internationally, examples of indirect reuse are well documented and, in some cases, reaches significant proportions. Hunt (1977) indicates that the Windhoek water reclamation in Windhoek, Namibia contributes up to thirty percent of the local water supply. Consequently, the residents of this community have been consuming some proportion of treated wastewater over an extended period of time.

Mueller (1977) indicates that under low flow conditions, the Ruhr River in West Germany can contain up to ninety percent treated wastewater. Overall, in West Germany, approximately ten to thirty percent of the water treated from surface sources is reclaimed wastewater. Hart (1977) indicates that indirect reuse is wide spread in South Africa. He reports case studies in which the proportion of treated wastewater in some water supply sources reached levels up to fifty percent. Eden (1977) summarizes the degree of indirect reuse in Great Britain and, in particular, the Thames River Basin. In the lower reaches of the Thames, under average flow conditions, the water supply for the City of London contains nearly fourteen percent wastewater effluent. Under low flow conditions, this proportion can increase significantly.

## Criteria for Evaluating Water Quality

In summary, the use of contaminated surface sources, or indirect reuse, is a wide-spread phenomenon in the United States and world-wide, but monitoring of most indirect reuse situations is incomplete. Where available, water quality data from the case studies mentioned could be used to compare with the levels of parameters observed in the EEWTP finished water.



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## CHAPTER 2

### CONCLUSIONS

The objective of the EEWTP project was to evaluate the technical feasibility of using the Potomac River estuary as a supplemental water supply source for the Metropolitan Washington Area to meet potential water shortages that might occur during severe droughts.

This chapter presents the conclusions of this evaluation, based on the results of two years of water quality monitoring. Three treatment process combinations were investigated during the two-year monitoring program as summarized in Table 2.0-1.

TABLE 2.0-1  
SUMMARY OF TREATMENT PROCESS COMBINATIONS MONITORED  
DURING THE TWO-YEAR OPERATION OF THE EEWTP

Phase	Processes	Duration
Phase IA	Alum coagulation, flocculation, sedimentation, intermediate disinfection with chlorine, dual-media gravity filtration, granular activated carbon (lignite based with fifteen minute empty-bed contact time), free chlorine disinfection.	16 March 1981 to 16 March 1982 52 weeks
Phase IB	As above with ozone in place of chlorine as intermediate oxidant/disinfectant.	17 March 1982 to 7 July 1982 15 weeks
Phase IIA	Lime coagulation, flocculation, sedimentation, recarbonation, dual-media gravity filtration, granular activated carbon (bituminous based carbon, thirty minute empty-bed contact time), ozone disinfection, chloramine disinfection.	17 July 1982 to 1 February 1983 28 weeks
Phase IIB	Same process as IIA. Decreased monitoring of influent to permit data evaluation of final report.	1 February 1983 to 15 March 1983 6 weeks

## Conclusions

The key issues addressed by the EEWTP project were as follows:

1. Selection of the appropriate blend of treated wastewater and Potomac River estuary water for the EEWTP influent to simulate the estuary water quality expected under drought conditions.
2. Acceptability for human consumption of the finished water produced by the EEWTP treatment combinations.
3. Process performance and reliability of the selected treatment combinations monitored during the two-year program with respect to control of those water quality parameters known to affect the aesthetic quality of the finished water and known or suspected to pose potential health risks to consumers.
4. Estimated costs of a full-scale estuary water treatment plant using those treatment combinations demonstrated to be technically feasible for producing a water of quality acceptable for human consumption.

The conclusions summarized below address each of these issues.

### SELECTION OF INFLUENT WATER QUALITY

Selection of the appropriate mixture of Blue Plains nitrified effluent and Potomac River estuary water was based on simulating water quality in the upper reaches of the estuary during drought conditions. The Dynamic Estuary Model (DEM), developed by EPA and calibrated for the Potomac River estuary was used for water quality simulation. Only those water quality parameters that do not undergo transformations in the water body (i.e., are conservative) were modeled because of uncertainties in the rates of transformation of most water quality parameters of potential health concern. These parameters included total dissolved solids (TDS), and many of the dissolved inorganic ions.

1. An equal blend (1:1) of treated wastewater and Potomac River estuary water was selected to simulate the expected water quality conditions in the Potomac River estuary at Chain Bridge, (a possible location of an estuary water treatment plant) under 1930 drought conditions with projected water supply demands for the year 2030.
2. The 1:1 blend was found to be a conservative simulation of expected water quality in the estuary at Chain Bridge, based on a comparison of water quality projections developed by the Dynamic Estuary Model (DEM), and the water quality observed in the blended influent.

### EVALUATION OF FINISHED WATER QUALITY

Within the limits of analytical techniques used on this project, the process combinations tested in the EEWTP (see Table 2.0-1) were shown to be capable of producing a finished water of quality suitable for human consumption.

## Conclusions

The finished waters from the three process combinations monitored were of acceptable quality for human consumption when compared to the primary and secondary drinking water regulations. For those parameters not regulated as well as other parameters of health or aesthetic concern, the EEWTP finished waters were observed to be of comparable or superior quality to those in the local WTPs.

For several water quality parameters, EEWTP levels exceeded the highest levels observed in the finished waters of three major MWA water treatment plants. For most of these parameters, however, the potential increase in health risks was judged to be negligible. Conclusions regarding the acceptability for human consumption based on levels of the key water quality parameters in the EEWTP finished waters are presented below by parameter group.

### PHYSICAL-AESTHETIC PARAMETERS

The key physical-aesthetic water quality parameters include turbidity, color, odor, and pH, parameters that have been included in either the primary or secondary drinking water regulations.

1. The three treatment process combinations monitored (Phases IA, IB and IIA) produced a finished water quality that rarely exceeded the Maximum Contaminant Levels (MCLs) for turbidity, and color, but frequently exceeded the MCL for odor. Although levels of pH were lower than the standard of pH 6.5 during the first few months of Phase IA operation adjustments in plant operation maintained finished water pH between the desired limits of 6.5 to 8.5.
  2. Geometric mean values of turbidity in the finished waters during all phases of operation were less than the highest geometric mean turbidity value in one of the local water treatment plants, as demonstrated by appropriate statistical comparisons.<sup>1</sup>
  3. Odor levels during Phase IA operation exceeded the secondary MCL threshold odor number of 3 TON in more than 95 percent of the samples. However, the odor testing panel was judged to be especially sensitive, and comparison with other panel results or standards is not valid. Thus, for this parameter, comparison of EEWTP values with values from the local WTPs was selected as the best basis for judging acceptability of the finished water quality with respect to odor. Such comparisons indicated that EEWTP odor levels were generally comparable to levels observed in local water treatment plants, although the geometric mean value exceeded the highest geometric mean odor level in one local plant during this phase of operation.
- 
1. Hypothesis testing was used to determine if the geometric mean values of water quality parameters in the EEWTP finished waters were significantly different compared to geometric mean values of the same parameters observed in the monitored local water treatment plants. The difference was considered to be statistically significant based on a five percent level of significance using the standard Student's t-test. This meant that there was a five percent chance that a false conclusion may have been inferred from the results of the hypothesis testing.

## Conclusions

4. The Phase IIA process reduced the odor levels considerably, with the geometric mean value during this phase of operation being significantly less than the highest value observed in a local plant. More than eighty percent of the odor samples during this phase had levels lower than the levels observed in one local plant.

### MAJOR CATIONS, ANIONS, AND NUTRIENT PARAMETERS

This parameter group includes eighteen inorganic parameters, three of which are included in the primary drinking water regulations (nitrate, sodium, and fluoride), and three of which are included in the secondary regulations (chloride, sulfate, total dissolved solids). Cyanide is also included in this group, as it is currently being considered for inclusion in the regulations because of potential adverse health effects.

1. In general, the finished water quality from the EEWTP during all phases of operation exhibited higher levels than the local plants for the parameters included in this group, a consequence of increased levels of dissolved salts in the treated wastewater portion of the blended influent, and the inability of the process combinations tested to remove these dissolved salts.
2. The levels of nitrate in three percent of the EEWTP finished water samples exceeded the primary MCL of 10 mg/L-N, during Phase IA. In all cases, this occurred when the blended influent consisted of nitrified effluent only.
3. Nitrate levels in the EEWTP finished waters were significantly higher than values observed in the local water treatment plants. The 90th percentile values of nitrate observed during the three phases of operation reached 9 mg/L-N, compared to the primary MCL of 10 mg/L-N. The 90th percentile values observed also match the maximum projected value of nitrate expected in the estuary during drought conditions. Because the high nitrate levels would provide almost no safety factor for this parameter compared to the MCL, the levels of nitrate represent a potential health issue should an estuary plant be constructed.
4. In addition to nitrate, the arithmetic mean values of those parameters of health or aesthetic significance in this parameter group were significantly greater than the highest arithmetic mean value observed in the local water treatment plants. These parameters include total dissolved solids, sulfate, chloride and sodium. Cyanide levels in the EEWTP were low (<0.003 mg/L) and not significantly different from the local water treatment plants. The levels of sodium exceeded the suggested EPA optimum level of 20 mg/L, but the observed levels were similar to median values observed in water systems in the U.S. None of the observed levels of these parameters are expected to pose significant adverse health risks to consumers, however.

## Conclusions

### TRACE METAL PARAMETERS

Twenty-four individual metals were included in this parameter group, eight of which are included in the primary drinking water regulations (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) and four in the secondary regulations (copper, iron, manganese, and zinc).

1. For those metals of health or aesthetic significance, the geometric mean values in the EEWTP finished waters during one or more of the operational phases exceeded the highest geometric mean value observed in the local plants only for the following metals: mercury, manganese, nickel, and zinc. The observed arithmetic and geometric mean values for mercury were below the MCL, however, and not considered to pose increased health risks. The geometric mean mercury levels during Phase IIA operation were reduced below the highest geometric mean observed in one local water treatment plant.
2. With the exception of mercury and manganese, concentrations of metals in the EEWTP finished waters never exceeded the specified maximum contaminant levels. Only during Phase IA of operation did the mercury levels exceed the MCL (three samples or about one percent of the total samples taken). The 90th percentile value for mercury was 0.0007 mg/L, less than one-half of the MCL of 0.002 mg/L.
3. During Phase IA operation, the secondary MCL for manganese was exceeded in 34 percent of the samples. Oxidant addition (permanganate in Phase IA and ozone in Phase IB) combined with adjustments to pH were successful in reducing manganese to levels consistently below the MCL.

### RADIOLOGICAL PARAMETERS

The monitored radiological parameters included gross alpha, gross beta, tritium and strontium-90, all of which are included in the NIPDWR.

1. Levels of these parameters in the finished waters from the EEWTP never exceeded the MCLs.
2. Gross beta radionuclides in the EEWTP finished waters were greater than the levels observed in the local water treatment plants during all of the EEWTP operational phases. Levels of strontium-90 and tritium were well below the MCLs, and were not at levels expected to cause any measurable increase in adverse health risks.

### MICROBIOLOGICAL PARAMETERS

This parameter group consisted of seven parameters; viruses, parasites, Salmonella bacteria, endotoxin, standard plate count, fecal and total coliforms. Only total coliforms are included in the primary drinking water regulations. These parameters have known or potential acute health effects when present in drinking water.

## Conclusions

1. Although detected in the blended influent, no viruses, parasites or Salmonella bacteria were detected in the finished waters produced by the EEWTP.
2. Standard plate count levels were generally low in the EEWTP finished waters (median value less than 1 colony/ml), during all phases of operation. Levels were significantly lower than the highest geometric mean values observed in two of the three local water plants, and well below the National Research Council recommended level of less than 100 colonies/ml for treated waters obtained from heavily contaminated sources.
3. During Phase IA operation, fecal and total coliform levels in the EEWTP finished waters exceeded the levels observed in the local water treatment plants. Although total coliform levels never exceeded the primary MCL of 1 MPN/100 ml, positive coliform counts were observed in over seventy percent of the samples. These results were due primarily to the presence of high ammonia concentrations and insufficient levels of free chlorine during the first four months of the Phase IA operation. Improved process performance after the first four months of operation reduced the coliform levels below 0.1 MPN/100 ml in ninety percent of the samples. It should be noted that the high volume coliform sampling technique provided a detection limit of 0.02 MPN/100 ml, approximately two orders of magnitude lower than the limit normally used in monitoring of water treatment plants in the U.S.
4. The Phase IIA process reduced the EEWTP fecal and total coliform levels below that observed during Phase IA. The percent positive samples were only slightly above that observed in the local water treatment plants. Over ninety percent of the samples were less than the detection limit of 0.02 MPN/100 ml.

## ORGANIC PARAMETERS

Of the 149 primary (targeted) compounds specifically monitored in this parameter group, only seven compounds (four pesticides, two herbicides and total trihalomethanes) are included in the primary drinking water regulations. Another six volatile organic chemicals are currently under consideration for inclusion in the regulations. Organic parameters monitored during this project include three categories; surrogate parameters (total organic carbon (TOC) and total organic halides (TOX)); primary or targeted organic compounds (compounds targeted for analysis using standards for confirmed identification and quantitation), and secondary or non-targeted compounds (tentative identification, approximate quantification). The latter category included an additional 300 organic compounds detected in influent waters and the finished waters.

1. The MCLs for pesticides and herbicides were never exceeded in any of the finished waters. The regulated pesticides and herbicides were not detected in the EEWTP finished waters.
2. Total trihalomethanes (TTHM) in the EEWTP finished waters never exceeded the values observed in the local water treatment plants, with



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OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
POTOMAC ESTUARY E. (U) MONTGOMERY (JAMES M) CONSULTING  
ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

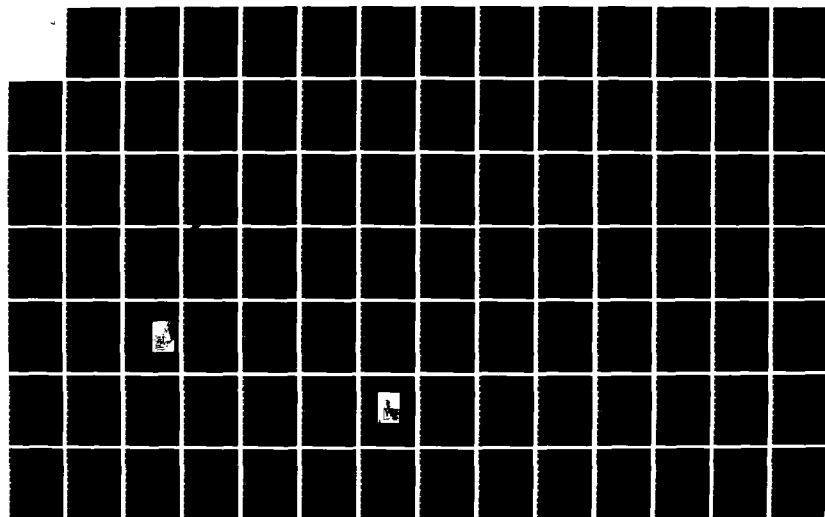
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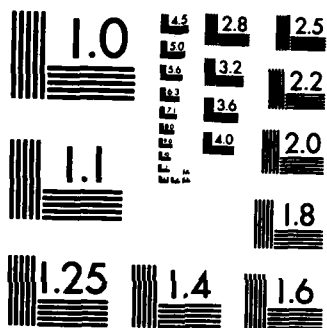
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

## Conclusions

geometric and arithmetic mean values significantly less than at all three local water treatment plants.

3. For all other targeted organic compounds, only thirteen compounds were quantified frequently enough to permit quantitative estimates of sample population statistics. With the exception of the trihalomethanes, the estimated geometric means of the other quantified compounds were less than 1 µg/L (one part per billion).
4. The observed levels of all but three monitored organic compounds in the EEWTP finished waters were lower than values observed in the finished waters from the local water treatment plants.
5. For those synthetic organic chemicals (SOCs) for which an EEWTP finished water had higher estimated geometric mean concentrations (PCE, naphthalene, and 1,3/1,4-Xylene), the EEWTP values were 0.05 µg/L or less. The chronic health risks associated with these levels can be assumed to be negligible. For example, the  $10^{-6}$  risk level for PCE is 4.5 µg/L, approximately 100 times greater than the estimated geometric mean in EEWTP finished waters.
6. The numbers of targeted and non-targeted (secondary) organic compounds detected at least once in the finished waters were observed to be lower in the EEWTP finished waters than in the local water treatment plants.
7. Total organic halide, a measure of the total quantity of halogenated organic compounds in the finished waters, was lower in the EEWTP finished waters than in the local finished waters by a factor of three to ten. Lowest values were observed during the Phase IIA process, due to the elimination of free chlorine from the process.
8. Based on observed concentration levels of the targeted compounds and other tentatively identified SOCs in the finished waters from the EEWTP, it is concluded that the water quality produced by all three process combinations would be of equal or better quality than that of the local plants for compounds which could be detected and identified by the techniques used on this project.
9. Because only a small fraction of the organic compounds included in the total organic carbon and total organic halide measurements can be detected by currently available analytical techniques, it is not currently possible to evaluate the absolute risks associated with ingestion of the finished waters produced by the EEWTP, or by other water treatment plants.

## TOXICOLOGICAL PARAMETERS

The two in vitro toxicological parameters monitored in the EEWTP were the Ames Salmonella microsome test and a mammalian cell transformation test using a special mouse cell line (C3H/10T1/2). These tests represent two of the tests recommended by the National Research Council (NRC) Committee on

## Conclusions

Water Quality Criteria for Reuse, for determination of the relative acceptability of a drinking water for human consumption, regardless of the source water quality. Neither of these parameters is currently regulated. In addition, the absolute values of the test results cannot currently be used to estimate potential health risks. Finally, it is difficult to compare results observed on this project with values reported in other finished drinking waters because of non-standardized sampling and analytical protocols. Thus, results can only be discussed based on comparisons between sampling sites specific to this project.

1. Positive Ames assay results, as measured by either the specific activity or the mutagenic ratio (two measures of mutagenic activity), were observed in the finished waters from both the EEWTP and the local water treatment plants. The number of positive assays in both Salmonella tester strains (TA 98 and TA 100) was lower in all of the EEWTP finished waters than in the local water plants. This was based on more than twenty-five assays conducted during the Phase IA process and more than twenty assays during the Phase IIA process.
2. Although positive assay results were observed in the EEWTP finished waters, the health implications of these results are unknown. However, because the frequency of positive mutagenic assays was lower in the EEWTP finished waters than in the finished waters of the local water treatment plants, it is concluded that EEWTP finished waters would not increase potential chronic health risks identified by the Ames assay. With respect to this toxicological parameter, the EEWTP finished waters are judged acceptable for human consumption.
3. Median values for the specific activities (revertants/L) in the EEWTP finished water during all phases of operation were slightly lower than values observed in the local plants for both Salmonella tester strains. These results again indicate the relative acceptability of the finished waters for human consumption.
4. Of the 23 to 25 mammalian cell transformation assays completed at each finished water site, three samples in the EEWTP finished waters and one to three samples in each of the local water plants (a total of six positives in the local plants) were positive for transformation activity. Where positive samples were observed, the number of plates with transformed cells was low, and generally similar to results observed in the local water treatment plants.
5. Based on the comparative results of the mammalian assays, it is concluded that the EEWTP finished waters did not indicate any increase in potential chronic health effects which may be detected by transformation assays compared to the three local water treatment plants.

## PROCESS PERFORMANCE

During the two-year operation of the EEWTP, three treatment process combinations were evaluated as to their technical feasibility for producing a water acceptable for human consumption. Each process combination was monitored

## Conclusions

extensively to determine the capabilities of individual processes for controlling water quality parameters with known or suspected health effects. The process combinations have been summarized in Table 2.0-1.

### PHASE IA

1. The finished water from the Phase IA process combination exhibited three water quality problems, compared to the finished water quality in the local water treatment plants; high odor levels, high manganese levels, and high and fecal total coliform levels.
2. The process combination tested during Phase IA was demonstrated to be a technically feasible combination for producing a finished water with acceptable quality, provided that appropriate levels of process chemicals are added to maintain target pH levels following sedimentation and target free chlorine residual levels following final disinfection.
3. To reduce total coliforms to acceptable levels, a free chlorine residual greater than 2.5 mg/L following 60 minute contact with a pH of 7.4 to 7.7 was required.
4. To control soluble manganese levels below the secondary MCL of 0.05 mg/L, control of pH between 7.5 and 8 combined with an oxidant (potassium permanganate) added ahead of coagulation was required.
5. High odor levels in Phase IA were reduced by maintaining the finished water pH above 7, and the final free chlorine residual above 2.5 mg/L.
6. During the winter months (December through March), ammonia levels in the EEWTP influent reached values of 1-2 mg/L-N, due primarily to disruption in the nitrification facilities at Blue Plains. Breakpoint chlorination prior to gravity filtration was required to permit free chlorine disinfection following GAC adsorption. Fluctuations in ammonia levels during these months and the required high chlorine doses caused several water quality problems including low pH values, the need for increased amounts of NaOH, an increase in potential corrosivity of the finished water, several high odor samples in the finished water (TON>50), and high levels of TOX in the GAC influent, leading to more rapid exhaustion of the GAC for TOX removal.
7. The Phase IA process combination exhibited satisfactory process reliability in meeting all the MCLs in the primary drinking water regulations. The 90 percentile values for all parameters included in the regulations were generally a factor of two or more lower than the MCL with the exception of nitrate.
8. The Phase IA process combination exhibited lower process reliability compared to Phases IB and IIA in meeting the secondary MCLs for odor and manganese. Both of these water quality problems can be controlled by appropriate process operating strategies, however.

## Conclusions

### PHASE IB

1. In the second process combination tested, Phase IB, improved process reliability was obtained for control of manganese by the addition of ozone ahead of the gravity filters. Maintenance of the target free chlorine residual ( $>2.5$  mg/L with a pH of 7.5) also significantly improved the process reliability for reduction of total coliforms.
2. The process combination tested during Phase IB was demonstrated to be a technically feasible process when treating an influent water of the quality observed. Under conditions of high influent ammonia levels, however, this process combination would likely experience difficult process control problems in achieving breakpoint chlorination. It is likely that under these conditions, finished water quality might exhibit unacceptable levels of total coliforms in the finished water. Thus, this process was not considered to be sufficiently reliable for producing a water quality acceptable for human consumption under influent water quality conditions similar to that observed during the full year of monitoring.

### PHASE IIA

1. The Phase IIA combination was demonstrated to be a technically feasible process for producing a finished water with acceptable quality, under all observed influent water quality conditions, and all operating conditions tested.
2. Process reliability for Phase IIA was superior to that demonstrated for Phases IA and IB with respect to total coliforms and manganese. Odor levels in Phase IIA were also lower than observed in the alum processes, but levels still exceeded the secondary MCL threshold odor number of 3 TON. The high odor levels were attributed to the conditions of the analytical test, especially with respect to the sensitivity of the odor panel as discussed. The geometric mean odor levels in the finished water from Phase IIA were lower than the highest geometric mean levels in the local water treatment plants.

## COSTS

Capital and annual costs have been estimated for a hypothetical 200 MGD estuary water treatment plant using the processes monitored in the Phase IA and Phase IIA treatment combinations. Because of uncertainties in the location and operating characteristics of any estuary water treatment plant, costs are summarized for the treatment plant only, excluding influent and finished water treatment plant components that would be needed for an actual estuary plant. Costs are based on continuous operation at the full 200 MGD design capacity.

1. Capital costs for the Phase IA and Phase IIA processes are approximately \$122 and \$174 million, respectively (April 1983 dollars).
2. Annual unit costs, based on the operating strategies used at the EEWTP (e.g., actual carbon usage rate) and including amortization (eight percent,

## Conclusions

twenty years), are \$0.34/1,000 gallons and \$0.48/1,000 gallons, for the Phase IA and Phase IIA processes, respectively. Operation and maintenance costs account for approximately fifty percent of the unit costs.

3. Annual unit costs for the Phase IA process are approximately twice the costs of a conventional water treatment plant treating a river water source without the use of granular activated carbon.
4. Some cost reductions in the GAC process could be achieved in the actual operation of a full-scale estuary water treatment plant by selection of less conservative regeneration criteria for the GAC. It has been shown that operation of GAC contactors in parallel, with a target finished water TOC level of 2 mg/L-C (the regeneration criteria used during Phase IA) could reduce the carbon usage rates used in the above cost estimates up to sixty percent.
5. If GAC regeneration is based on TOC criteria for the blended effluent of many columns operated in parallel, a TOC goal of 1 mg/L may be more prudently compared to the goal of 2 mg/L. Under this more conservative regeneration criterion, unit operating costs are estimated to be \$0.32/1,000 gallons and \$0.41/1,000 gallons for the process combinations from Phases IA and IIA, respectively.
6. If air stripping in a packed tower is included in the Phase IA process combination as an additional treatment barrier for control of volatile organic chemicals, the unit costs would increase by about ten percent to \$0.37/1,000 gallons.
7. Should it be necessary to remove several dissolved inorganic parameters of potential health or aesthetic concern (nitrate, sodium, hardness, TDS), a reverse osmosis process would be added to treat half of the 200 MGD plant capacity. The unit costs for Phase IA combination with RO replacing GAC would be \$0.69/1,000 gallons.

## CHAPTER 3

### PLANT MONITORING PROGRAMS

During the two years of operation, a comprehensive monitoring program was carried out to evaluate the performance of the EEWTP and to compare the EEWTP finished water to the finished water from three major water treatment plants (WTP) in the Metropolitan Washington Area (MWA). The overall monitoring consisted of the Routine Water Quality Testing Program (RWQTP) and the Operational Data Collection System (ODCS).

The RWQTP and ODCS programs were carried out in a routine and scheduled fashion throughout the duration of the project. Sample frequency and location tables presented in this chapter are based on a combination of the RWQTP and ODCS. The major difference between the two programs is that the ODCS data was primarily used on a daily basis to operate the EEWTP processes. The RWQTP samples, most of which were composites, were shipped to the off-site laboratory for many different analyses. RWQTP samples were collected at a frequency of no more than once per day; whereas, the ODCS analyses (pH, temperature, turbidity, electroconductivity, dissolved oxygen and disinfectant residual) were conducted by the EEWTP plant operators several times each day on grab samples.



## **SECTION 1**

### **MONITORING PROGRAM, 16 MARCH TO 31 NOVEMBER 1981**

#### **BACKGROUND**

The initial monitoring program began on 16 March 1981. This was based on a February 1979 Special Study Report, "Sampling and Analytical Requirements, Experimental Estuary Water Treatment Plant" (MPI, 1979). The program was slightly modified at initiation to account for sampling logistics at the EEWTP and the three local water treatment plants designated as WTP1, WTP2, WTP3.

#### **SAMPLING FREQUENCIES AND LOCATIONS**

The parameters analyzed, their sampling frequencies and site locations are presented in Table 3.1-1. Sample frequency definitions are provided in Table 3.1-2. The list of primary trace organic compounds monitored is found in Chapter 4 (Table 4.4-3). Sample collection for several microbiological and toxicological parameters began on dates later than 16 March 1981, as shown below.

<u>Parameters</u>	<u>Initial Sampling Date</u>
Enteric Virus	22 April 1981
Parasites	21 May 1981
Ames Test	3 June 1981
Salmonella	22 June 1981
Mammalian Cell Transformation	10 July 1981

Because of the importance of these parameters for evaluation of finished water quality, most samples missed between 16 March and the first sampling date were resampled later in the project.

# Monitoring Program, 16 March to 31 November 1981

TABLE 3.1-1  
PLANT MONITORING PROGRAM  
16 March 1981 to 31 November 1981

	Blue Plains Nitrified Effluent	Potomac River Estuary	Blend- ed Inf.	Recarb- onation Tank Eff.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EEMTP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
PHYSICAL/AESTHETIC												
Temperature	H2	H2	H2					H2	DR	DR	DR	
pH	H4	H4	H4	H4	H12	H12	H4	H4	DR	DR	DR	
Dissolved Oxygen	D6	D6	D6	D6			H12	D6	DR	DR	DR	
Particulate Parameters												
Turbidity	H4	H4	H2	H2	H4		H4	H2				
Total Suspended Solids	DC	DC	DC	DC	DC		DC					
Asbestos	MC	MC	MC	MC	MC			MC	MC	MC	MC	FG
Color	DC	DC	DC	DC	DC			DC	DC	DC	DC	MC
MBAS								DC	DC	DC	DC	
Odor								DC	DC	DC	DC	
Taste								DC	DC	DC	DC	
Chlorine Residual (Free & Total)					H4			DC	DC	DR	DR	
INORGANIC												
Major Cations and Trace Metals <sup>1</sup>					DC			DC	DC	DC	DC	FG
Anions												
Total Dissolved Solids	DC	DC	DC	DC				DC	DC			
Electroconductivity			H2	H2				DC				
Alkalinity		DC	DC	DC			DC	DC	DC	DC	DC	
Bromide		DC	DC	DC				DC	DC	DC	DC	
Chloride		DC	DC	DC				DC	DC	DC	DC	
Cyanide		DC	DC	DC				DC	DC	DC	DC	
Fluoride		DC	DC	DC				DC	DC	DC	DC	
Iodide		DC	DC	DC				DC	DC	DC	DC	
Silica		DC	DC	DC				DC	DC	DC	DC	
Sulfate		DC	DC	DC				DC	DC	DC	DC	
Nutrients												
Nitrogen, Ammonia		DC	DC	DC				DC	DC	DC	DC	
Nitrogen, Nitrate/Nitrite			DC	DC			DC	DC	DC	DC	DC	
Nitrogen, Total Kjeldahl <sup>1</sup>			DC	DC			DC	DC	DC	DC	DC	
Phosphorus, Ortho-Phosphate			DC	DC			DC	DC	DC	DC	DC	
Radiochemical <sup>2</sup>		MC			MC		DC	MC	MC	MC	MC	

TABLE 3.1-1 (Continued)  
PLANT MONITORING PROGRAM  
16 March 1981 to 31 November 1981

	Blue Plains Nitrified Effluent	Potomac River Estuary	Recarb- onated Tank Inf.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EETP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
<b>MICROBIOLOGICAL</b>											
Total Coliform	FG	FG				FG	FG	FG	MG	MG	
Fecal Coliform	FG	FG				FG	FG	FG	MG	MG	
Standard Plate Count	FG	FG				FG	FG	FG	MG	MG	
Endotoxin	MG	MG				MG	MG	MG	MG	MG	
Salmonella	MG	MG				MG	MG	MG	MG	MG	
Viruses	MX	MX		MX		MX	MX	MX	MX	MX	
Parasites	MX	MX		MX		MX	MX	MX	MX	MX	
<b>ORGANIC</b>											
Total Organic Carbon											
(Off-site)											
(On-site)											
Total Organic Halide	DC		DC	H8	H8	DC	DC	DC	DC	DC	
Synthetic Organics	DC		DC			DC	DC	DC	DC	DC	
Liquid/Liquid Extraction											
(Off-site)											
(On-site)											
Base/Neutral and Acid Extractions			SC	SG	SG	SC	SC <sup>3</sup>	SC	SC	SC	
Volatiles Organics Analysis			SG			SG	SG				
Herbicides			R3			R3	R3	R3	R3	R3	
Pesticides and PCBs			RC			RC	RC	RC	RC	RC	
			R3			R3	R3	R3	R3	R3	
			R3			R3	R3	R3	R3	R3	
<b>TOXICOLOGICAL</b>											
Ames											
Mammalian Cell Transformation											
							WX	WX	WX	WX	
							MX	MX	MX	MX	

1. Major cations and trace metals: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, tin, titanium, vanadium and zinc; also hardness at the following sites: Potomac River Estuary, EETP Blended Influent, Final Carbon Column Effluent, EETP Finished Water and WTP1 Finished Water.

2. Radiological parameters: gross alpha, gross beta, and tritium

Radium is analyzed in all samples for which gross alpha (plus 2-sigma) exceeds 5 pCi/L.

Strontium-90 is analyzed in all samples for which gross beta (plus 2-sigma) exceeds 8 pCi/L.

3. At these sites, weekly grabs were scheduled for seven day terminal THM analysis.

TABLE 3.1-2  
SAMPLE FREQUENCY DEFINITIONS

**Hourly**

- H4 Grab every 4 hrs
- H2 Grab every 2 hrs
- H8 Grab every eight hours
- H12 Grab every 12 hrs

**Daily**

- DC Daily 24 hr Composite (7 samples/week)
- DG Daily Grab (7 samples/week)
- DR Reading/Measurement every 24 hours obtained from off-site

**Five Days per Week (Daily except weekends)**

- FC Daily 24 hr Composite (5 samples/week)
- FG Daily Grab (5 samples/week)

**Alternate Days**

- AC Every Other Day 24-hour Composite (4 samples/week)

**Semiweekly**

- SC Semiweekly 24 hr Composite
- SG Semiweekly Grab

**Weekly**

- WC Weekly 24 hr Composite
- WG Weekly Grab
- WX Weekly Concentration

**Biweekly**

- BC Biweekly 24 hr Composite
- BX Biweekly Concentration

**Triweekly**

- RC Triweekly 24 hr Composite
- R3 Triweekly 72 hr Composite

**Monthly**

- MC Monthly 24 hr Composite
- MG Monthly Grab
- MX Monthly Concentration

**Quarterly**

- QG Quarterly grab (one sample every four months)

## **SECTION 2**

### **MONITORING PROGRAM, 1 DECEMBER 1981 TO 15 MARCH 1982**

#### **BACKGROUND**

After several months of operation with the initial program, a review was conducted to identify potential improvements which could be implemented for the balance of the first year monitoring program. This review was based on the following findings:

1. The monitoring frequency of parameters with greater potential for adverse effects could be increased while reducing the sampling frequency for less significant parameters without sacrificing the ability to evaluate process performance of the EEWTP.
2. Engineering analysis of the project data identified several parameters which could be sampled less frequently but at additional sites to improve monitoring of in-plant processes.
3. Statistical analyses and process modeling efforts revealed several parameters for which the sampling frequency was inadequate; for other parameters, it was determined that less frequent sampling would provide sufficient information.

The revised program was initiated on 1 December 1981 and operated until the beginning of the second year of plant operation, on 16 March 1982.

#### **REVISED MONITORING PROGRAM**

The revised sampling program is presented in Table 3.2-1. Definitions for frequency abbreviations are listed in Table 3.1-2. The major highlights of the revised program can be summarized as follows:

1. To facilitate the characterization of influents, most parameters were sampled at three locations (Blue Plains Nitrified Effluent, Potomac River Estuary and Blended Influent). This provided improved baseline data on the sources of contaminants to the EEWTP, which could be used to compare with assumptions used in the modeling of influent quality (see Chapter 6).
2. EEWTP sampling at intermediate process sites was enhanced to improve process monitoring.

Monitoring Program, 1 December 1981 to 15 March 1982

3. Increased sampling at the three local WTPs expanded the availability of baseline data for comparison of MWA finished water to the EEWTP finished water.
4. Sampling frequencies were reduced for a number of parameters, including the trace metals, major cations, anions, and nutrients.
5. All composite samples were based on a 24-hour compositing period.
6. Endotoxin, fecal coliforms and taste were dropped.
7. Additional sites for the Ames test were sampled for investigation of changes in mutagenic activity through the EEWTP treatment process.
8. Closed-loop stripping analysis was instituted.

# Monitoring Program, 1 December 1981 to 15 March 1982

TABLE 3.2-1  
PLANT MONITORING PROGRAM  
1 December 1981 to 16 March 1982

	Blue Plains Nitrified Effluent	Potomac River Estuary	Blend- ed Inf.	Recarb- onation Tank Eff.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EEWTP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
PHYSICAL/AESTHETIC												
Temperature	H2	H2	H2	H4	H12	H4	H4	H2	DR	DR	DR	
pH	H4	H4	H4	H4	H12	H12	H12	H4	DR	DR	DR	
Dissolved Oxygen	DG	DG	DG	DG				D6				
Particulate Parameters												
Turbidity	H4	H4	H2	H2	H4	H4	H4	H2	DR	DR	DR	
Total Suspended Solids	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WG
Asbestos	WC	WC	WC	WC	WC			WC	WC	WC	WC	
Color	WC	WC	WC	WC	WC			WC	WC	WC	WC	
MBAS	WC	WC	WC	WC	WC			WC	WC	WC	WC	
Odor								WC	WC	WC	WC	
Chlorine Residual (Free & Total)					H4	WC	WC	H4	DR	DR	DR	
INORGANIC												
Major Cations and Trace Metals <sup>1</sup>	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SG
Anions <sup>2</sup>	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	
Nutrients <sup>3</sup>	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	
Radiochemical <sup>4</sup>												
Gross Alpha	WC	WC	WC	WC				WC	WC	WC	WC	
Gross Beta	WC	WC	WC	WC				WC	WC	WC	WC	
Tritium	WC	WC	WC	WC				WC	WC	WC	WC	
MICROBIOLOGICAL												
Total Coliform	WG	WG	WG	WG	WG	WG	WG	FG	FG	FG	FG	
Standard Plate Count	WG	WG	WG	WG	WG	WG	WG	FG	FG	FG	FG	
Endotoxin	QG	QG	QG	QG	QG	QG	QG	QG	QG	QG	QG	
Salmonella	MG	MG	MG	MG	MG	MG	MG	MG	MG	MG	MG	
Parasites	MX	MX	MX	MX	MX	MX	MX	MX	MX	MX	MX	
Virus Identification	MX	MX	MX	MX	MX	MX	MX	MX	MX	MX	MX	

TABLE 3.2-1 (Continued)  
PLANT MONITORING PROGRAM  
1 December 1981 to 16 March 1982

	Blue Plains Nitrified Effluent	Potomac River Estuary	Blend- ed Inf.	Recarb- onation Tank Eff.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EEWTP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
ORGANIC												
Total Organic Carbon (Off-site)	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	
(On-site)												
Total Organic Halide	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	
Synthetic Organics												
Liquid/Liquid Extraction	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	
(Off-site)												
Acid Extraction	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	
Base/Neutral Extraction	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	
Volatile Organics Analysis	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	
Closed Loop Stripping	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	
Herbicides	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	
Pesticides and PCBs	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	
TOXICOLOGICAL												
Ames	WX	WX	WX	WX	WX	WX	WX	WX	WX	WX	WX	
Mammalian Cell Transformation												

1. Major cations and trace metals: Same constituents as in Table 3.1-1.

2. Anions: Same constituents as in Table 3.1-1.

3. Nutrients: Same constituents as in Table 3.1-1.

4. Radiological Parameters: Same as in Table 3.1-1.



### **SECTION 3**

#### **MONITORING PROGRAM, 16 MARCH 1982 TO 16 MARCH 1983**

##### **BACKGROUND**

A statistical evaluation of data from the first year's monitoring program was done to evaluate the suitability of the sampling frequencies for characterizing process performance and finished water quality. A revised program to cover the second year of operations was initiated. This section describes the second year program and provides documentation of the method of approach, statistical techniques and results related to the development of the revised program.

##### **SAMPLING FREQUENCIES AND LOCATIONS**

The second year monitoring program is presented in Table 3.3-1. Definitions for frequency abbreviations were listed in Table 3.1-2. All composite and grab sampling at WTP1, WTP2, and WTP3 ceased on 1 February 1983. All sampling from the Blue Plains and Potomac River sites ended on the same day, as did asbestos sampling at all locations. The remaining on-site composite and grab sampling continued until 16 March 1983. All virus, parasite and toxicological concentrations ended on 15 February 1983.

The major program changes were as follows:

1. Fecal coliform monitoring was reinstated.
2. Endotoxin was reinstated at finished water sites.
3. Blue Plains Nitrified Effluent and Potomac River Estuary locations were dropped from virus and parasite monitoring. Also, Gravity Filter Effluent and Final Carbon Column Effluent sites were dropped from virus monitoring.
4. Virus monitoring frequency at the EEWTP Blended Influent and Finished Water sites was increased from monthly to weekly concentrations.
5. The sampling frequency for acid extractables, base/neutral extractables, herbicides, and pesticides/PCBs was decreased from tri-weekly to monthly composites.
6. Liquid-liquid extraction sampling frequency was increased from semi-weekly to every other day (four samples/week).

Monitoring Program, 16 March 1982 to 16 March 1983

TABLE 3.3-1  
PLANT MONITORING PROGRAM  
16 March 1982 to 16 March 1983

	Blue Plains Nitrified Effluent	Potomac River Estuary	Blended Inf.	Recarb- onation Tank Eff.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EEMTP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
PHYSICAL												
Temperature	H2	H2	H2	H4	H12	H4	H4	H2	DR	DR	DR	
pH	H4	H4	H4	D6		H12	H12	H4	DR	DR	DR	
Dissolved Oxygen	D6	D6	D6					D6				
Particulate Parameters												
Turbidity	H4	H4	H2	H2	H4	H4	H4	H2	DR	DR	DR	
Total Suspended Solids	WC	WC	WC	WC	WC	WC	WC	WC	MC	MC	MC	WG
Asbestos	WC	WC	WC	WC	WC			WC	WC	WC	WC	
Color	WC	WC	WC	WC	WC			WC	WC	WC	WC	
MBAS	WC	WC	WC	WC	WC			WC	WC	WC	WC	
Odor								WC	WC	WC	WC	
Chlorine Residual (Free and Total)								WC	WC	WC	WC	
Ozone Residual (liquid)								FG	DR	DR	DR	
								FG5				
INORGANIC												
Major Cations and Trace Metals <sup>1</sup>	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SG
Cyanide	SC	SC	SC					SC	SC	SC	SC	
Anions <sup>2</sup>	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	
Nutrients <sup>3</sup>												
Radiochemical <sup>4</sup>												
Gross Alpha	BC	BC	BC	BC				BC	BC	BC	BC	
Gross Beta	BC	BC	BC	BC				BC	BC	BC	BC	
Tritium								MC	MC	MC	MC	
MICROBIOLOGICAL												
Total Coliform	WG	WG	WG	WG	WG		FG	FG	FG	FG	FG	
Fecal Coliform	WG	WG	WG	WG	WG		FG	FG	FG	FG	FG	
Standard Plate Count	WG	WG	WG	WG	WG		FG	FG	FG	FG	FG	
Endotoxin								QG	QG	QG	QG	
Salmonella	MG	MG	MG	MG	MG		MG	MG	MG	MG	MG	
Virus Identification								WX	WX	WX	WX	
Parasites								MX	MX	MX	MX	

TABLE 3.3-1 (Continued)  
PLANT MONITORING PROGRAM  
16 March 1982 to 16 March 1983

	Blue Plains Nitrified Effluent	Potomac River Estuary	Blended Inf.	Recarb- onation Tank Eff.	Dual Media Filtration Eff.	Lead Carbon Column Eff.	Final Carbon Column Eff.	EENTP Finish. Water	WTP1 Finish. Water	WTP2 Finish. Water	WTP3 Finish. Water	Sludge
ORGANIC												
Total Organic Carbon (Off-site)	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	
(On-site)				HB								
Total Organic Halide	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	
Synthetic Organics												
Liquid/Liquid Extraction (Off-site)	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	AC	
Acid Extraction	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	
Base/Neutral Extraction	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	
Volatile Organics Analysis	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	
Closed Loop Stripping	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	BC	
Herbicides	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	
Pesticides and PCBs	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	
TOXICOLOGICAL												
Ames	BX	BX	BX		BX		BX	BX	BX	BX	BX	
Mammalian Cell Transformation								MX	MX	MX	MX	

1. Same constituents as in Table 3.1-1 except antimony, beryllium, cobalt, molybdenum, thallium and tin were dropped.

2. Anions: Same constituents as in Table 3.1-1.

3. Nutrients: Same constituents as in Table 3.1-1.

4. Radiological parameters: Same constituents as in Table 3.1-1.

5. Sample taken at post-ozonation site (prior to ammonia and chlorine addition points).

7. Ames test sampling frequency was reduced from weekly to bi-weekly concentrations. However, additional sampling was conducted to make-up for scheduled samples which were not collected during the first year plant monitoring programs.
8. Six metals were dropped: antimony, beryllium, cobalt, molybdenum, thallium and tin.
9. Ozone residual monitoring was started at the ozonation effluent site.
10. Gross alpha and beta sampling was reduced from weekly to bi-weekly composites.
11. The two EEWTP influents were dropped from tritium monitoring.

#### PROGRAM DEVELOPMENT

The method of approach for evaluation of the sampling program for the last year of operation consisted of the following tasks:

1. Characterization of the existing data.

Water quality data from the first year of operations were reviewed to assess the availability of data for specific parameters. Descriptive statistics were estimated and attempts were made to fit probability distribution functions to several parameters. Special cases where values were below analytical detection limits were investigated. The existence of serial correlation in many data sets was confirmed and investigated.

2. Development and application of statistical techniques.

Criteria for interpretation of water quality data were reviewed in light of the particular significance of individual analyses to the sampling program. Statistical parameters of importance were defined as well as appropriate techniques for estimation of those parameters. Where data were available, the techniques were applied to estimate the number of samples required to meet the criteria. Sample sizes were converted to sampling frequency and a preliminary sampling program was developed.

3. Preparation of final sampling program.

Following a critical review of the sampling program with respect to logistics, cost and engineering judgment, a final recommended version was prepared.

#### CHARACTERIZATION OF EXISTING DATA

The first step for this task was to review the project water quality data base to assess the availability of data. This review indicated that analytical results for a number of important water quality parameters were below the limit of detection in most or all samples analyzed. Most standard statistical techniques are not appropriate for manipulation of this type of data. This prevented direct use of these data for estimation of the desired sample size. A summary of the parameters in this category is presented in Table 3.3-2. Special approaches

were devised for some of these parameters, where there were still a reasonable number of quantified samples. For others, selection of sample frequency was based solely on engineering judgment or logistical considerations.

TABLE 3.3-2  
CATEGORIES OF PARAMETERS WITH INSUFFICIENT  
POSITIVE VALUES FOR DIRECT CALCULATION  
OF SAMPLE FREQUENCIES

- Microbiological
  - Parasites
  - Salmonella
  - Viruses
- Toxicological
  - Mammalian
- Inorganic
  - Metals
    - Beryllium
    - Cobalt
    - Molybdenum
    - Thallium
    - Tin
    - Titanium
- Organic
  - Liquid/Liquid Extraction Compounds
    - Carbon Tetrachloride
    - Tetrachloroethylene
    - Trichloroethylene
  - Base/Neutral and Acid Extractables
  - Pesticides/Herbicides/PCBs
  - Volatile Organics Analysis Compounds
    - All except THMs
- Radiological
  - Tritium

For parameters where most of the data were quantifiable, an appropriate frequency distribution (e.g., normal, log-normal) was chosen to characterize the behavior, as discussed in Appendix B, Section 2. The log-normal probability distribution was selected for use in the analysis of sampling frequency. Techniques utilized for the evaluation are described in detail in Appendix B, Section 2.

In general, the data for the finished water from the EEWTP were used in the calculations of sample frequency. The primary reason for this was because this sampling location was most often used for comparison with other locations, such as the EEWTP influents or product waters from other local WTPs. For

some parameters, these data were insufficient for the calculation. Alternative locations were used to make inferences about statistical behavior for a given parameter. For example, virus measurements in the influent to Water Factory 21 in Orange County, California were used to characterize the spread factor of enteric viruses. For asbestos analyses, data from the EEWTP Blended Influent were used to estimate a spread factor because of the small number of positive identifications in the finished water. The primary reason for this approach was to be as quantitative as possible in the evaluation of the sampling program even where EEWTP finished water sample results were not amenable to quantitative analysis.

#### STATISTICAL TECHNIQUES FOR EVALUATING SAMPLING FREQUENCY

The objectives of a water quality sampling program are largely dependent on the water quality impacts of a given parameter, such as chronic and acute health effects. For this project, statistical procedures were developed for estimation of the sample size required to meet the different proposed statistical objectives. These objectives, and the procedures utilized to determine an associated sampling requirement, are fully described in Appendix B (Section 2). The different objectives are briefly summarized below.

##### Characterization of the Geometric Mean

One objective of a sampling program may be to characterize the geometric mean with a certain desired accuracy. Toward this end, it is possible to calculate a sample size required to achieve a given range of the 95 percent confidence interval about the geometric mean. For this project, this technique was utilized to determine, from available sampling data, the sample frequency required to estimate the geometric mean with upper and lower 95 percent confidence bounds within a factor of two. This technique, although arbitrary, provides reasonable criteria for the sampling of water quality parameters which are consistently below an established goal.

##### Hypothesis Testing - Comparison with a Goal

Another objective in determining a required sample size is to ensure that there are sufficient samples to demonstrate that the mean falls below a given goal. In this case, it is necessary to have enough samples to "test" the hypothesis that the geometric mean is indeed below the goal with a given level of confidence, say 95 percent. The appropriate statistic for testing the hypothesis that the population geometric mean falls below a goal is a t-test as described in detail in Appendix B.

##### Hypothesis Testing - Comparison of Finished Waters

For some parameters it is possible to show that the EEWTP finished water has concentrations significantly below values in the MWA water supplies. The procedure for this is the t-test for the difference in means of two populations. This test is useful for parameters in which the mean value in the EEWTP final effluent is not far below the goal, but the mean values for the alternate water

sources are higher. It is also useful where no goal for a parameter has been set, but health risk is an issue. A sample size can be calculated for the EEWTP finished water and the other finished water sites required to prove a significant difference, as described in Appendix B.

#### Characterization of Exceedance Frequency

One important objective of a sampling program is to characterize the frequency with which a given goal is exceeded. This is especially applicable to parameters for which acute toxicity or aesthetic quality are associated with the goal. By assuming that the probability measured in preliminary data will be valid for future samples, one can calculate the number of samples required to narrow the upper 95 percent confidence limit on the probability of exceeding the goal to an arbitrary bound. For example, it may be desirable to ensure a sample size sufficiently large to place the 95 percent upper confidence limit on the probability of exceeding the goal to less than five or ten percent.

When no samples are observed to exceed the goal, the sample size required to set the upper 95 percent confidence limit to an arbitrary level is constant:  $n = 29$  for ten percent,  $n = 59$  for five percent. This is one way to set a minimum sample size for those parameters which seem to fall clearly below the goal. This technique is one of frequency substitution based on binomial distribution of the data, and is described more fully in Appendix B.

#### Additional Issues

Application of each of the above techniques is further complicated by additional factors related to:

1. Concentrations below the analytical limits of detection.
2. Data which are not truly randomly distributed but, rather, serially correlated over time.

Techniques for dealing with both of these issues are fully discussed in Appendix B.

### RESULTS

Project sampling data collected between 16 March 1981 and 1 December 1981 were analyzed by the previously described statistical techniques in order to optimize the sampling program for the second year of operations. The second year monitoring program has already been presented in Table 3.3-1 and represents the application of the statistical findings, together with considerations of sampling and shipping logistics and available funds. As described below, engineering judgment played a very large role in determining the final program.

#### Characterization of Geometric Mean

This objective was assumed whenever calculations were feasible. The basic objective of the sample size determination was to provide sufficient samples to

characterize the 95 percent confidence limits around the geometric mean to within a spread of two. This approach was applied whenever quantifiable data were available in reasonable amounts (at least fifteen percent of the samples). Two cases of application were utilized in this approach:

1. All values above the detection limit; use of all samples to determine required sampling.
2. Some values below the detection limit; required sampling estimated by both of the following methods:
  - a. Geometric mean and spread factor for full sample estimated from linear regression.
  - b. Statistics based only on quantified samples; estimated total sample size based on characterizing the quantifiable values.

In general, the serial correlation of the data led to very large required sample sizes to meet this objective, some of which could not be met within the time frame of the project. The auto-correlation is largely due to process or event related variances in the data which, to some extent, are predictable and explainable. Thus, it is not clear that the objective of characterizing the mean within arbitrary limits is necessary or desirable.

#### Hypothesis Testing - Comparison with a Goal

This objective was utilized for twelve parameters which were consistently below EEWTP operational goals.

In general, the calculation yields very low numbers of required samples (n) for parameters with geometric means more than one standard deviation below the goal, and very large ones for geometric means less than 0.1 standard deviations below goal. Some examples are a calculated n of 4 for TOC, 13 for turbidity, and 110 for total coliforms. This estimate of n may serve then as another minimum value. The low values for n demonstrate again that it is often easy to prove that the mean water quality satisfies a goal. For some parameters this may be sufficient. In general, however, more information is desired.

#### Hypothesis Testing - Comparison of Finished Waters

Procedures to meet this objective were not as meaningful as originally anticipated, primarily because of either 1) a lack of quantified data or 2) difficulties with the objective. Specifically, similarities in many instances between EEWTP and local WTP finished waters made it very difficult to prove an hypothesis of difference between the two. The number of samples required to prove such an hypothesis is often excessive. Further consideration suggested that this objective was overly restrictive and, in many cases, it was necessary to accept a conclusion that central tendencies of the different populations may not be significantly different.



### Characterization of Exceedance Frequency

This objective is most interesting for parameters which frequently exceeded criteria or goals. For parameters on this project which usually meet the goals, the number of samples required to meet this objective is generally quite small. Proving exceedance less than ten percent (with 95 percent confidence) requires only 29 samples if all previous values have met the criteria. This number can be utilized as a context for decisions about sampling frequency. Otherwise, statistical procedures related to characterization of exceedance frequency were not utilized in revising the monitoring program.

### Results - Estimated Samples Sizes

The calculated required sample sizes for representative water quality parameters are presented in Table 3.3-3. The calculated sample sizes are based on the procedures which were outlined in this section as described at the bottom of the table.

### Discussion - Required Sampling Frequency

The calculated required sample sizes were converted to sampling frequency based on the overall constraint that the second year sampling program take place over the period of exactly one year and that samples be limited to 24-hour composites or daily grab samples, since all calculations were based on this type of sampling frequency. This section presents a discussion of the results obtained in this analysis.

Physical/Aesthetic Parameters. Results for color show that the data were strongly serially correlated. This suggests possible seasonality or change in the performance of the EEWTP. Most values are below the detection limit after July 1981. The data tend to be very lumpy due to the nature of the analytical test for color. Note from Table 3.3-3 that the data after July 1981 indicate much smaller sample sizes were required. Based on demonstrating the geometric mean as below the goal, weekly sampling in the EEWTP effluent was maintained.

Analysis of the MBAS samples showed that the highest reported value was 20% of the secondary drinking water standard. For this reason, it was sampled only monthly. No attempt was made to conduct an evaluation of sample size for chlorine residual or dissolved oxygen as these parameters were used for operator data collection process control.

Analysis of the asbestos samples was conducted on EEWTP Blended Influent samples because only 2 of 29 available effluent samples had quantifiable values. For chrysotile fibers in the blend the size required to characterize the geometric mean indicated increased sampling to semi-weekly. Finished water sampling was also increased to semi-weekly for comparative purposes.

Monitoring Program, 16 March 1982 to 16 March 1983

TABLE 3.3-3  
CALCULATED REQUIRED SAMPLE SIZE<sup>1</sup>

Parameter	Procedure			
	(A)	(B)	(C)	(D)
<u>Microbiological</u>				
Total Coliforms		64	46	7 (0.1 MPN/100ml)
Virus: BGM cell line <sup>2</sup>		62	45	
RD cell line		100	59	
<u>Physical/aesthetic</u>				
Asbestos <sup>3</sup>		150	88	
Color		167	138	272 (15 cu)
Color, after July 1981		44	118	68 (15 cu)
Odor <sup>4</sup>	76			
<u>Inorganic</u>				
Total Dissolved Solids	176			234 (500 mg/L)
Alkalinity	196			
Bromide		104	83	
Fluoride	28			
Cyanide		111	112	
Nitrate and Nitrite		56	56	64 (10 mg/L)
Sulfate	312			176 (250 mg/L)
Calcium	244			
Arsenic		550	445	24 (0.05 mg/L)
Lead		943	385	45 (0.05 mg/L)
Mercury		94	85	10 (0.002 mg/L)
<u>Radiological</u>				
Gross Beta	22			6 (8 pCi/L)
<u>Organic</u>				
Total Trihalomethanes		246	197	22 (100 µg/L)
Total Organic Carbon	104			61 (3.0 mg/L)
Total Organic Halogen		365	106	152 (150 µg/L)

Based on data in EEWTP finished water except as noted.

Procedures:

- Characterization of geometric mean; all values above detection limit.
- Characterization of geometric mean; mean and spread factor estimated from linear regression.
- Characterization of geometric mean; based on subset of quantifiable values.
- Sample size required for testing the hypothesis that the geometric mean lies below a selected goal. The assumed operational goal for the calculation is shown in parentheses beside the calculated sample size.

- Data for statistical analysis taken from samples collected between 16 March 1981 to 1 December 1981.
- Virus analyses at influent to Water Factory 21 in Orange County, California.
- Asbestos measured in blend tank effluent.
- Geometric mean for odor in existing data is above goal.

Results for the odor analyses indicate a weak auto-correlation. The geometric mean of odor samples at the EEWTP was 15 TON. This exceeds the secondary drinking water standard of 3 TON. Based on the sample size required to characterize the geometric mean within a factor of 2, sampling frequency was increased to semi-weekly samples. No attempt was made to evaluate pH, temperature, total suspended solids, or turbidity. These analytical tests are operator data collection system process control parameters.

Major Cations, Anions and Nutrients. Analysis of the data for a number of the inorganic parameters including alkalinity, sulfate, total dissolved solids, bromide, fluoride, cyanide, the major cations, and nitrate/nitrite showed variable degrees of auto-correlation ranging from weak to very strong. This is likely due to dependence on seasonality or flow in the Potomac estuary. As a result large correction factors for auto-correlation were applied to the calculated required sample sizes. For many of these parameters the sample sizes were so large that it would be impossible to take enough daily composite samples within a year to adequately characterize the geometric mean. In the general case of inorganics, characterization of the geometric mean is not a desirable objective of the sampling program due to the seasonal variability of the parameters. Therefore, the frequency of sampling for minerals, major cations, and nutrients was maintained at semi-weekly.

Trace Metals. Evaluation of trace metals results showed that some metals had very few values above the detection limit. Based on this, six metals (beryllium, cobalt, molybdenum, thallium, tin, and antimony) were dropped. Two other metals, arsenic and lead, were examined in detail. The evaluation indicated that they were both strongly auto-correlated. As a result, very large sample sizes are required to adequately characterize the geometric mean because of very high correction factors. Because metals appeared to be highly event related, it was felt that characterization of the geometric mean to within specified limits was not an appropriate objective. Therefore, metals were maintained at the existing sampling frequency of semi-weekly.

Radiological Parameters. The only radiological parameter to be evaluated was gross-beta. Although available data were limited, sample size required to characterize the geometric mean indicated that frequency could be decreased to bi-weekly. Data for gross-alpha indicated that the highest observed value was one percent of the maximum contaminant level. No attempt was made to evaluate tritium or strontium-90 because of insufficient data or because most values were not quantifiable.

Microbiological Parameters. Results for total coliforms indicated that there was a strong auto-correlation for coliforms in all EEWTP finished water data. However, much of the auto-correlation could be removed by splitting the data into populations based on a change in disinfection strategy at the plant. Statistical evaluation then revealed that characterization of the geometric mean and/or testing the hypothesis of meeting the goal could be met with sampling decreased to weekly. However, because it was also necessary to assess effects due to changes in the disinfection process for second year operation, no change was made.

Evaluation of viruses was based on Orange County Water District Water Factory 21 plant influent measurements at a time when the source was an activated sludge process effluent. This approach was taken because at the time statistical analysis was performed, no positive identifications had been made in EEWTP monthly samples. The Water Factory 21 data suggested that the frequency of sampling should be increased to weekly in order to increase the confidence in the characterization of the influent water quality.

With respect to parasites, none were detected in the EEWTP finished water, therefore, no statistical evaluation was attempted. Similarly, analysis of the Salmonella data indicated that these were not detected in the EEWTP finished water, although some influent samples were positive. Therefore, no statistical evaluation of Salmonella was attempted.

The standard plate count (SPC) test was also not evaluated, as samples for this analysis are logistically linked with total coliform samples. The recommendations for coliform sampling were applied to SPC monitoring.

Organics. Of the compounds detected by liquid/liquid extraction, only total trihalomethanes were evaluated because of availability of data. The behavior of this parameter is not unlike the highly auto-correlated metals. Based on a sample required to characterize the geometric mean of total trihalomethanes, the liquid/liquid extraction sampling was increased to alternate days.

Data for both total organic carbon and total organic halogen were very strongly auto-correlated. This is likely due to the strong dependence on breakthrough phenomena in the activated carbon adsorption process. Based on the sample size required to characterize the geometric mean, the sampling frequency of alternate days for both total organic carbon and total organic halide was maintained.

Examination of the database for priority pollutants and synthetic organic chemicals showed that no acid extractables, pesticides, herbicides or PCBs had been detected. In addition, only a few base/neutral compounds were found. As a result, no attempt was made to conduct a statistical evaluation of sample size for these analytical techniques, and sampling was reduced to a minimum frequency of one sample per month. Of the priority pollutant protocols, only some results for volatile organics analysis were available. However, there were insufficient data to conduct a statistical evaluation. Because some organics were detected with this technique, there was no basis for change in the sampling frequency of bi-weekly. No attempt was made to evaluate sampling frequency for closed-loop stripping analysis because of insufficient data at the time of evaluation.

#### FINAL SAMPLING PROGRAM

The revised program was developed by first incorporating the recommendations of the statistical evaluation and then modifying sample frequencies based on logistical considerations engineering judgment and cost consideration. One significant finding of this exercise was the apparent undesirability of the use of characterization of the geometric mean as a sampling objective because many

Monitoring Program, 16 March 1982 to 16 March 1983

of the parameters were so strongly auto-correlated. Due to the limited scope of this task, it was not possible to conduct detailed modeling of the seasonal influent on these parameters or specific phenomena associated with such processes as granular activated carbon adsorption. Therefore, the recommended sample size for these parameters was based largely on engineering judgment and logistics.

## **REFERENCES**

Malcolm Pirnie, Inc. (MPI), Special Study Report for U.S. Army Corps of Engineers, Baltimore District, "Sampling and Analytical Requirements, Experimental Estuary Water Treatment Plant" (February 1979).

## **CHAPTER 4**

### **ANALYTICAL METHODS AND SAMPLING**

This chapter discusses the laboratory facilities used to conduct water sample analyses, the specific analytical procedures used and the sampling methods implemented during the project. The goal of the analytical and sampling program was to attain satisfactory analytical precision and accuracy while minimizing analytical artifacts and sample contamination within budgetary constraints. This required a thorough quality control/quality assurance program which is described in Section 6 of this chapter.

Physical laboratory facilities, on-site and off-site, are described in Section 1.

Analytical methods described in Section 2 are divided into major parameter group subsections; 1) physical/aesthetic, 2) major cations, anions and nutrients, 3) trace metals, 4) radiological parameters, 5) microbiological parameters, 6) trace organics and 7) toxicological parameters. Detection limits, precision and accuracy data and sampling methods are covered in Sections 3 through 5.

## SECTION 1

### LABORATORY FACILITIES

All analytical work was performed at the EEWTP (on-site) laboratory in Washington, D.C. and at Montgomery Laboratories (off-site) in Pasadena, California, with the exception of the tritium analysis<sup>1</sup> and high resolution mass spectrometry analysis.<sup>2</sup> The off-site analytical work was done at the off-site laboratory with government leased equipment. Close coordination between the EEWTP and the off-site laboratory assured consistency and continuity in sample handling and analytical methods.

#### ESTUARY EXPERIMENTAL WATER TREATMENT PLANT

The on-site laboratory staff coordinated all routine monitoring and assisted plant operators and engineers during various additional process optimization and special testing studies. Laboratory responsibilities included 1) collecting samples, 2) preparing samples for shipment, 3) conducting certain inorganic, organic and microbiological analyses, 4) concentrating large volume water samples for enteric virus, parasite, and toxicological assays and 5) providing analytical support for the operations and engineering staffs.

#### GENERAL FACILITIES

The on-site laboratory consists of an organics laboratory and a general laboratory utilized for sample preparation and storage, inorganics analyses and microbiological analyses.

The general laboratory was equipped with a chemical fume hood, gas, vacuum and compressed air fixtures, flammable liquid and acid storage cabinets and a glassware preparation area equipped with a dishwasher. Samples were stored at 4°C in a 6 ft by 10 ft walk-in cold box which was thermostatically controlled and provided with continuous temperature monitoring and recording equipment.

The organics laboratory was equipped with a gas-chromatograph and a total organic carbon (TOC) analyzer. The laboratory was in a separate room from the general laboratory.

1 EAL Corporation, Richmond, California

2 Harvey Laboratories, Charlottesville, Virginia and University of North Carolina at Chapel Hill



## Laboratory Facilities

### MAJOR ANALYTICAL EQUIPMENT

The major pieces of analytical equipment are shown in Table 4.1-1.

TABLE 4.1-1  
MAJOR ANALYTICAL EQUIPMENT AT EEWTP

<u>Instrument</u>	<u>Manufacturer/Model</u>	<u>Analysis</u>
Gas chromatograph	Varian Vista 44 with CDS-401 data system	Liquid-liquid extrac- tions, trihalomethanes
Total organic carbon analyzer	Dohrmann-Envirotech DC-80	TOC
Particle size analyzer	HIAC PA-720	Particle size distribution
Spectrophotometer	Bausch and Lomb Spec 21	Ozone, UV-TOC correlation
Amperometric titrator	Wallace and Tiernan	Chlorine and ozone residuals
Turbidimeter	Hach ratio turbidimeter	Turbidity
Ion analyzer	Orion 501	pH, dissolved oxygen, ammonia

### OFF-SITE LABORATORY

The off-site laboratory received an average of 150 RWQTP samples each week from the EEWTP creating nearly 1200 distinct weekly analytical data points for entry into the project database. The off-site laboratory was responsible for sample log-in, analyses, quality control, data storage and report generation. To manage and process the large sample inventory, the laboratory staff utilized company-wide mainframe computer resources and a Hewlett-Packard 3357B Laboratory Automation System (LAS). The focal point of the LAS system is the interactive Sample Information Management System (SIMS) software. The program has the following features:

- Sample log-in
- Sample tracking/organization
- Results acquisition
- Report acquisition
- Data validation/quality assurance
- Laboratory accounting

The major pieces of analytical equipment at the off-site laboratory are presented in Table 4.1-2.

# Laboratory Facilities

TABLE 4.1-2  
MAJOR ANALYTICAL EQUIPMENT AT THE OFF-SITE LABORATORY

Instrument	Manufacturer/Model	Analysis
Atomic absorption spectrophotometer	Perkin-Elmer 5500 AAS/ICP	Metals
Ion chromatograph	Dionex Model 16	Bromide
Mercury analyzer	Coleman MA550	Mercury
Continuous flow analyzers	Scientific Instruments	Anions, nutrients
Proportional counter	Tennelec Model 1000	Gross alpha, beta, Sr <sup>90</sup>
Transmission electron microscope	Zeiss EM-10 with Ortec EEDS-II	Asbestos
Gas chromatographs	1) Varian 3700 2) Varian 2400 3) Varian 6000 4) Finnigan 4000 GC/MS 5) Varian 4600 with Vista 401 chromatography system	Synthetic Organics (SOCs)
Total organic carbon analyzer	Xertex - Dohrmann DC-80	Total organic carbon
Total organic halide analyzer	Xertex - Dohrmann DC-20	Total organic halide
Closed-loop stripper	JMM	SOCs
HPLC	Varian 5000	SOCs

## SECTION 2

### ANALYTICAL METHODOLOGY

#### SELECTION OF METHODS

##### EPA APPROVED METHODOLOGY

Most of the analytical protocols were EPA approved methods taken from Standard Methods for the Examination of Water and Wastewater, 15th Edition (1981), Methods for Chemical Analysis of Water and Wastes, Environmental Protection Agency (1979) or The Federal Register published methods for organics analyses and Inductively Coupled Argon Plasma Emission Spectroscopy. A brief description of the method and the protocol reference is given for each parameter in Tables 4.2-1 through 4.2-7.

##### METHOD MODIFICATIONS

Approved methods were modified in several cases to improve precision, accuracy or specificity of the procedure. Modifications were also made, as in the case of acid methylation in the acid extractables procedure, in order to increase analytical sensitivity. Any major procedural modification is described in this chapter for each affected parameter or analysis.

##### SPECIALIZED ANALYSES

Certain analyses which are not commonly performed on water samples or are generally reserved for research applications were included in the monitoring program. These are called "specialized analyses". Although many of the specialized analyses are expensive and, therefore, not routinely conducted on drinking water, they are valuable for qualitatively or quantitatively identifying chemical and biological contaminants which may be of direct health concern. A detailed protocol for each analysis designated below is presented in Appendix A, Section 1. Although they are not necessarily considered to be specialized analyses, the following organics protocols are also included in the Appendix: pesticides/PCBs, LLE-trihalomethanes, base-neutral and acid extractables and total organic carbon.

- Enteric viruses
- Parasites
- Ames mutagenicity
- Salmonella
- Mammalian cell transformation
- Ion chromatography
- Particle size analysis
- Dihaloacetoneitriles
- Closed-loop stripping

## Analytical Methodology

- Steam distillation of organics
- Herbicides
- Anion/cation fractions of organics
- High pressure liquid chromatography
- Total organic halides
- Volatile organics
- Asbestos

### PHYSICAL/AESTHETIC PARAMETERS

The methods used for determining parameters which are classified as "physical/aesthetic" are listed in Table 4.2-1. These parameters do not easily fit into the other groupings. In addition, all parameters related to measuring the particulate contamination of water are included with this group, as are the operational parameters relating to disinfectant residual.

Particle size and asbestos were the only analyses which were not taken from EPA or Standard Methods protocols. The asbestos protocol was taken from an EPA interim procedure published in 1980. Asbestos concentrations were determined by filtering water samples through polycarbonate membrane filters to trap the fibers and then transferring the fibers to an electron microscope grid for counting under a transmission electron microscope at 20,000 times magnification. Particle size distribution was determined from the manufacturer's recommended procedure accompanying the HIAC PA-720 analyzer. Detailed protocols are found in Appendix A, Section 1.

### MAJOR CATIONS, ANIONS AND NUTRIENT PARAMETERS

#### GENERAL DESCRIPTION

All of the chemical constituents in this parameter group were determined using EPA or Standard Methods procedures, with the exception of bromide (by ion chromatography). Ion chromatography will be included in the next edition of Standard Methods. The ion chromatography procedure for bromide was chosen for its superior sensitivity and is described in Appendix A, Section 1. A complete methods list is shown in Table 4.2-2.

Ammonia, chloride, cyanide, fluoride, nitrate, total kjeldahl nitrogen, ortho-phosphate and sulfate analyses were automated with a continuous flow system using a Scientific Instruments Modular Continuous Flow Analyzer (CFA). The process consists of a module which automatically mixes reagents and samples in precisely measured quantities. A flow-through colorimeter determines the absorbance of the color complex formed which is then compared to a series of standards analyzed with the actual samples. The dual channel CFAs are capable of running up to sixty samples per hour for four parameters simultaneously.

TABLE 4.2-1  
PHYSICAL/AESTHETIC METHODS

Parameter	Method	Reference	Location of Analysis
Asbestos	Electron microscopy	EPA Interim, 1980	Off-site
Chlorine residual	Amperometric	EPA <sup>1</sup> 330.1	On-site
Color	Colorimetric	EPA 110.2	On-site
Dissolved oxygen	Membrane electrode	EPA 360.1	On-site
MBAS	Colorimetric	EPA 425.1	Off-site
Odor	Threshold odor number	EPA 140.1	Off-site
Ozone residual	Iodometric titration	APHA <sup>2</sup> 442	On-site
Particle size	Particle size analyzer	HIAC	On-site
pH	Electrometric	EPA 150.1	On-site
Taste	Threshold taste number	APHA <sup>2</sup> 211	Off-site
Temperature	Thermometric	EPA 170.1	On-site
Total suspended solids	Gravimetric	EPA 160.2	On-site
Turbidity	Nephelometric	EPA 180.1	On-site

1. EPA refers to Analytical Methods for Water and Wastewater Laboratories, Environmental Protection Agency, 1979.
2. APHA refers to Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980.

TABLE 4.2-2  
MAJOR CATIONS, ANIONS AND NUTRIENTS METHODS

Parameter	Method	Reference	Location of Analysis
Alkalinity	Automated methyl orange or manual titration	EPA <sup>1</sup> 310.2 or EPA 310.1	Off-site
Bromide	Ion chromatography	Dionex and APHA 400Z (16th edition)	Off-site
Calcium	Flame emission	APHA <sup>2</sup> 311A and Perkin Elmer manual	Off-site
Chloride	Automated ferricyanide	EPA 325.2	Off-site
Cyanide	Automated distillation/UV	EPA 335.3	Off-site
Electroconductivity	Specific conductance	EPA 120.1	On/Off-site
Fluoride	Automated complexone	APHA 413E	Off-site
Hardness	Ca + Mg addition	APHA 314A	On/Off-site
Iodide	Catalytic reduction	APHA 414B	Off-site
Magnesium	Flame AAS	APHA 318A	Off-site
Nitrate + Nitrite	Automated cadmium reduction	EPA 353.2	Off-site
Nitrogen, Ammonia	Automated phenate	EPA 350.1	Off-site
Nitrogen, Kjeldahl	Semi-automated block digester	EPA 351.2	Off-site
Phosphate (ortho-)	Automated ascorbic acid	EPA 365.1	Off-site
Potassium	Flame emission	APHA 322B	Off-site
Silica	Colorimetric	EPA 370.1	Off-site
Sodium	Flame emission	APHA 325B	Off-site
Sulfate	Automated methylthymol blue	EPA 375.2	Off-site
Total dissolved solids	Gravimetric or addition	EPA 160.1	On-site

1. EPA refers to Analytical Methods for Water and Wastewater Laboratories, Environmental Protection Agency, 1979.

2. APHA refers to Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980.

Alkalinity was initially determined using CFA procedures but was also determined by manual titration due to low values (less than 50 mg/L- $\text{CaCO}_3$ ) found at some sites.

Silica was determined by the yellow molybdosilicate colorimetric method. Iodide was determined colorimetrically by catalytic reduction of ceric ions. Magnesium was determined by atomic absorption spectrophotometry. Calcium, potassium and sodium were determined by flame emission spectroscopy using the atomic absorption unit in an emission mode following addition of lithium as an ionization suppressor.

#### METHOD MODIFICATION

The only method modified from Standard Methods or EPA protocols was calcium, which is normally determined by atomic absorption following lanthanum addition. Early investigations showed that the emission method, based on the Perkin-Elmer methods manual, provided equivalent precision and accuracy and was easier to use for the large number of samples being processed for all four major cations.

#### TRACE METAL PARAMETERS

In addition to the major cations previously cited (calcium, magnesium, sodium, and potassium), an additional 24 metals were monitored during this project. Most of the metals are present in only trace quantities ( $<1$  mg/L), but can be of great significance with respect to the potability of the water, both in terms of aesthetic appeal and health effects. Unlike the major cations, the trace metals have a negligible impact on the ionic balance. The EPA regulated metals are arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver.

Trace metals listed in Table 4.2-3 were determined by either Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Argon Plasma Spectroscopy (ICP). AAS procedures were taken from EPA methodologies. The ICP procedures were taken from Federal Register 44:69559-69564, 3 December 1979 (EPA Interim 200.7). All metals except mercury were determined as "total" metals following a nitric acid digestion/concentration. Mercury was determined on an unconcentrated sample.

TABLE 4.2-3  
TRACE METAL METHODS

Parameter <sup>1</sup>	Method	Reference
Aluminum	Inductively coupled plasma (ICP)	Federal Register, 2 1979
Antimony	Furnace AAS	EPA <sup>3</sup> 204.2
Arsenic	Furnace AAS	EPA 206.2
Barium	ICP	Federal Register, 1979
Beryllium	ICP	Federal Register, 1979
Boron	ICP	Federal Register, 1979
Cadmium	ICP (3/16/81-11/30/81)	Federal Register, 1979
	Furnace AAS (12/1/81-3/15/83)	EPA 213.2
Chromium	ICP (3/16/81-11/30/81)	Federal Register, 1979
	Furnace AAS (12/1/81-3/15/83)	EPA 218.2
Cobalt	ICP 3/16/81-(11/30/81)	Federal Register, 1979
	Furnace AAS (12/1/81-3/15/82)	EPA 219.2
Copper	ICP (3/16/81-11/30/81)	Federal Register, 1979
	Flame AAS (12/1/81-3/15/83)	EPA 220.1
Iron	ICP	Federal Register, 1979
Lead	Furnace AAS	EPA 239.2
Lithium	ICP (3/16/81-11/30/81)	Federal Register, 1979
	Flame AAS (12/1/81-3/15/83)	APHA <sup>4</sup> 317A
Manganese	ICP	Federal Register, 1979
Mercury	Cold vapor	EPA 245.1
Molybdenum	ICP	Federal Register, 1979
Nickel	ICP	Federal Register, 1979
Selenium	Furnace AAS	EPA 270.2
Silver	Flame AAS (3/16/81-11/30/81)	EPA 272.1
	Furnace AAS (12/1/81-3/15/83)	EPA 272.2



TABLE 4.2-3 (Continued)

## TRACE METAL METHODS

Parameter	Method	Reference
Thallium	Furnace AAS	EPA 279.2
Tin	ICP	Federal Register, 1979
Titanium	ICP	Federal Register, 1979
Vanadium	ICP	Federal Register, 1979
Zinc	ICP (3/16/81-11/30/81)	Federal Register, 1979
	Flame AAS (12/1/81-3/15/83)	EPA 289.1

1 Metals analyses were conducted at the off-site laboratory.

2. Federal Register, December 3, 1979.

3. EPA refers to Analytical Methods for Water and Wastewater Laboratories, Environmental Protection Agency, 1979.

4. APHA refers to Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980.

## ATOMIC ABSORPTION SPECTROPHOTOMETRY

### Principles

In atomic absorption spectrophotometry a sample is either aspirated into a flame (flame AAS) or electrically heated in a graphite tube (furnace AAS) to atomize the individual elements. A light beam is directed through the atomized sample into a monochromator and onto a detector that measures the amount of light absorbed by the atomized element of interest in the source (flame or furnace). Because each metal has its own characteristic absorption wavelength, a source lamp composed of that element is used as the light source. The amount of energy of the characteristic wavelength absorbed in the source is proportional to the concentration of the element in the sample. Because each metal has a characteristic wavelength for absorption, the method is relatively free of spectral or radiation interferences. The method exhibits high sensitivity for most of the metallic elements.

### Flame AAS

In flame AAS the atomization source is either an air-acetylene or nitrous oxide-acetylene flame. The sample is aspirated into the flame, which is oriented so that the light beam from the source lamp passes directly through the flame. In the high temperature of the flame (greater than 2,300°K), an element is atomized and absorbs light from the source lamp in proportion to its concentration. Flame AAS has detection limits in the 10 to 50 µg/L range for many metallic elements; however, for some elements present at µg/L or sub-µg/L range it is not sufficiently sensitive.

### Furnace AAS

Furnace AAS is 10 to 100 times more sensitive than flame AAS. Instead of a flame, the atomization source is a resistance heated graphite tube. A known volume (5-100 µl) of sample is pipetted into the tube, and the sample is dried by passing a low current through the tube. The tube is then heated to an intermediate temperature to char or ash the sample. Finally, a high current heats the tube to the atomization temperature of the element, and the absorbance is measured. Increased sensitivity occurs since the entire sample is atomized, rather than only the small fraction actually aspirated into the flame in flame AAS. The technique is much more sensitive to interferences than flame AAS, arising principally from non-specific light absorption in the confined area of the furnace. This interference is overcome by using background correction, in which light from a deuterium arc or tungsten source (broad spectrum) is also absorbed, and the difference between absorption of the broad spectrum light and the elemental source light is a measure of the concentration of the element.

In addition to non-specific absorption, the method is subject to matrix interferences and contamination (due to the low concentrations measured), and it is therefore necessary to match standard and sample matrices carefully and take extreme precautions for cleanliness in sample processing.

## INDUCTIVELY COUPLED ARGON PLASMA (ICAP)

### Principles

ICAP is a multi-elemental emission technique. The sample is aspirated into a plasma maintained at a temperature of 8-10,000°K by application of an RF discharge to a supply of argon. The sample then emits light at characteristic wavelengths for individual elements. The intensity of the emission at individual wavelengths is measured by using a photomultiplier detector and a scanning monochromator. The high temperature of the plasma ensures that linearity extends over several orders of magnitude and that interferences are reduced to a minimum.

ICAP provides advantages of speed in analysis due to its multi-elemental capability, permitting analysis of five or more elements per minute. ICAP can be used to determine all the elements normally determined by atomic absorption and is also particularly useful for refractory elements such as barium, boron, or aluminum which cannot be determined with a great deal of sensitivity by absorption techniques due to the low temperature of the flame or furnace.

### Operation

A multi-elemental standard is aspirated into the plasma at a rate of about 1 ml/min using a peristaltic pump. The wavelengths are scanned and the emission intensity at each wavelength measured. The samples are then aspirated and the emission intensity at each wavelength compared to the standard to determine elemental concentration. Background correction is accomplished by measuring emission intensity on either side of each peak and subtracting that from the peak emission.

## RADIOLOGICAL PARAMETERS

Methods for detecting radioactive species in water are given in Table 4.2-4.

Gross alpha and beta activity were measured by evaporation of a water sample onto a stainless steel planchet and counting in a thin-window proportional counter for sixty minutes. Activity in pCi/L was calculated by corrections for the efficiency of the detector as a function of solids content. Strontium was determined on samples with more than 8 pCi/L gross beta activity by precipitation of strontium carbonate and counting the beta activity in a low background thin-window proportional counter. Activity in pCi/L was calculated by corrections for the precipitation yield of strontium carbonate and detector efficiency. Tritium was determined by scintillation detection following distillation.

TABLE 4.2-4  
RADIOLOGICAL METHODS

Parameter	Method	Reference	Location
Gross alpha	Direct evaporation-alpha count	APHA <sup>1</sup> 703	Off-Site
Gross beta	Direct evaporation-beta count	APHA 703	Off-Site
Radium	Barium sulfate precipitation	APHA 705	Off-Site
Strontium-90	Strontium carbonate precipitation	APHA 704	Off-Site
Tritium	Distillation, scintillation	APHA 708	EAL <sup>2</sup>

1. APHA refers to Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980.

2. EAL Corporation, Richmond, California.

## TOXICOLOGICAL PARAMETERS

### GENERAL DESCRIPTION

Many short-term assays have been developed to screen environmental samples for mutagens and carcinogens. However, no single assay is capable of detecting all carcinogens and many investigators favor using a battery of short-term tests to gather toxicological data. Two of the more extensively used assays, Ames Salmonella/Mammalian-Microsome Test and Mammalian Cellular Transformation Assay, were selected as part of the Routine Water Quality Testing Program.

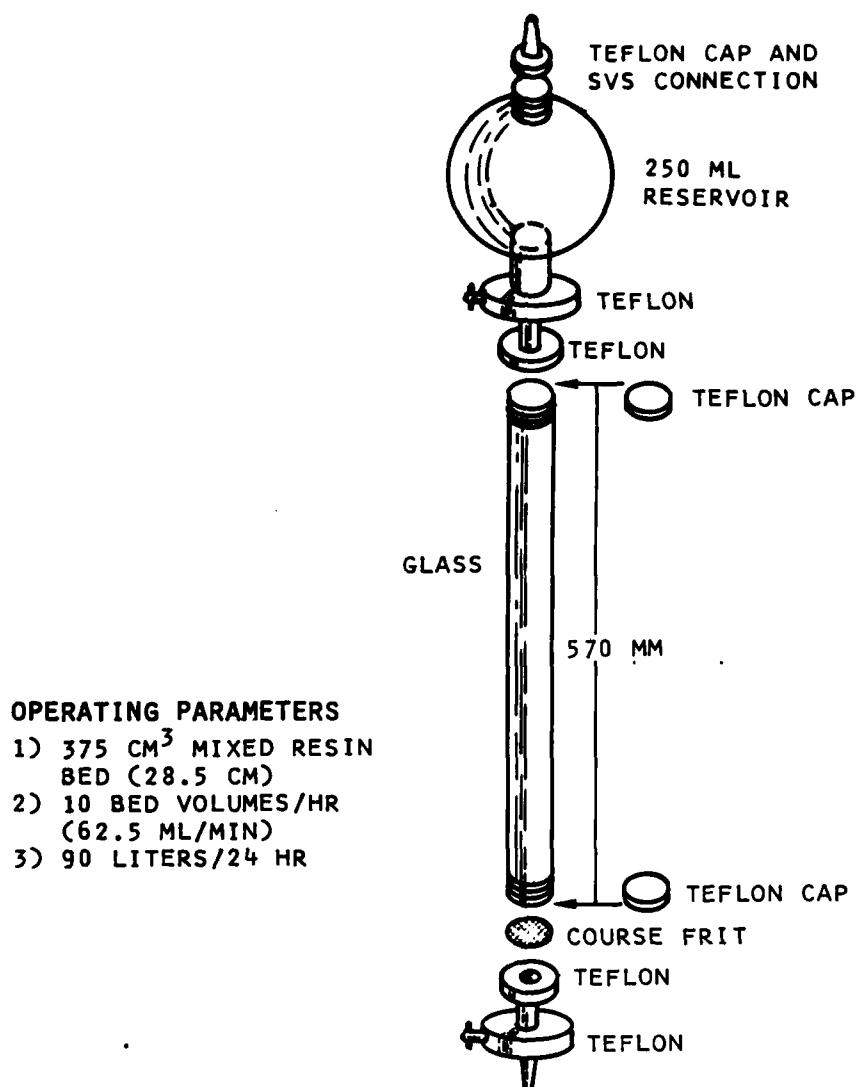
The Ames test developed by Dr. Bruce Ames at the University of California, Berkeley, is a simple bacterial bioassay for detecting structural changes in the DNA of individual genes, called gene mutations. In this test specifically constructed mutants of the bacterium Salmonella typhimurium are exposed to chemicals in a histidine-deficient agar medium. The bacteria lack an enzyme required to produce the growth-essential amino acid histidine and will not form colonies in the agar unless a reverse mutation occurs restoring histidine synthesis. If the bacteria are exposed to a chemical which mutates the correct sequence of the Salmonella DNA, the bacteria will again be able to synthesize histidine and grow into visible colonies in the histidine-deficient agar medium. The number of these revertant colonies is a measure of the mutagenic potency of the chemical.

The use of mammalian cells, as opposed to bacteria, has the advantage of being more closely related to human cells with respect to their DNA structure and metabolic activities, which may be more useful in interpreting test results. A mammalian cell transformation assay developed by Dr. Charles Heidelberger using a fibroblastic cell line C3H/10T1/2 derived from C3H mice (Reznikoff, Brankow and Heidelberger, 1973), was utilized for this project. In this assay, non-malignant cells are exposed to a chemical in vitro for 48 hours, and following several weeks of growth the cells are examined for morphological changes indicating transformation to malignant cells. When the transformed cells are injected into suitable hosts, a high correlation with tumorigenicity is often observed. In the C3H/10T1/2 system, morphologic cell transformation is characterized by the cells' loss of density-dependent inhibition, resulting in the formation of colonies, commonly called foci, in which the cells have piled up.

The "chemical" tested in these two assays was in actuality a mixture of organic compounds concentrated from up to 100 L of water by adsorption on XAD macroreticular resins. The resin concentration and organics extraction procedures are described below.

### SAMPLE CONCENTRATION AND ORGANICS EXTRACT PREP<sup>A</sup> RATION

Organic mixtures used for toxicology testing were concentrated from continuously flowing samples filtered through a combination of XAD-2 and XAD-7 macroreticular resins packed in an all glass and teflon column. The concentrator design is shown in Figure 4.2-1. The operating parameters were



**ORGANICS CONCENTRATOR**  
**FIGURE 4. 2-1**

## Analytical Methodology

187 cm<sup>3</sup> XAD-2 and 187 cm<sup>3</sup> XAD-7 in series, 60 ml/min flowrate (10 bed volumes/hr) and 24 hours run time (approximately 90-100 L total volume). Resin columns were shipped to the off-site laboratory, where the columns were extracted and the Ames and mammalian cell assays were conducted.

Columns were eluted with 250 ml of acetone which were then reduced to 1 ml by rotary evaporation. Dimethyl sulfoxide (DMSO) was added to bring the final extract volume up to 2 ml. Extracts were stored at -20°C in amber glass vials with teflon-lined caps until assayed.

Resins were cleaned by 24-hour Soxhlet extractions in methanol followed by acetone. Cleaned resins were stored under methanol.

### AMES TEST

The method used is essentially the same as the protocol by Ames, et al published in Mutation Research 31:347-364 (1975). Two tester strains of *S. typhimurium*, TA98 and TA100, were obtained from Dr. Bruce Ames at the University of California, Berkeley. Master plates were prepared in accordance with the Supplement to the Methods Paper, Ames, et al, Mutation Research 31:347-364 (1975). Isolated colonies from master plates were inoculated into Oxoid Nutrient Broth #2 and incubated with slight agitation at 37°C for 18 hours. This culture was used as the inoculum in the mutagenesis assay. Frozen permanent cultures stored at -70°C were used to generate new master plates. Quality control checks for the mutation integrity of the tester strains are described in Section 6.

In the mutagenesis assay, the following were added (in order) to 2.5 ml molten top agar at 45°C : test sample not exceeding 250 µl, 50 µl tester strain suspension, and 500 µl S-9 metabolic activation mix (when included). The contents were vortexed, overlayed onto a minimal glucose agar plate and incubated 48 hours at 37°C in a dark incubator. Duplicate plates were made for each concentration. Arochlor 1254-induced rat liver S-9 homogenate was used for metabolic activation. After 48 hours incubation, revertant colonies were counted manually (TA98) or with an automatic colony counter (TA100). Spontaneous reversion in the absence of the test extract was based on the average obtained from at least duplicate plates.

Total revertants were plotted against the equivalent liters of water sample inoculated in each concentration. A minimum of three doses were tested. The slope of the regression line (specific activity in revertants/liter) was calculated for each tester strain, with and without S-9 activation. The sample was considered mutagenic if the 95 percent confidence interval of the slope was greater than zero. Also, the mutagenic ratio (total revertants divided by the spontaneous revertants) was calculated at the dose having the highest average number of total revertants. Mutagenic ratios greater than or equal to 2.0 were considered positive mutagenic responses.

## MAMMALIAN CELL TRANSFORMATION

The mammalian cell transformation assay involved exposing monolayers of actively growing C3H/10T1/2 mouse embryo cells to the test material for 48 hours. The cells were rinsed and maintained at 37°C in five percent CO<sub>2</sub> for six weeks at which time the cells were stained with giemsa and examined with a dissecting microscope for morphologically transformed foci. Two classes of foci were identified. Type II foci show massive piling up into opaque multilayers in which criss-crossing is not pronounced. Type III foci are multi-layered criss-crossed arrays of densely stained cells.

Each sample was tested at three concentrations for transformation in twenty dishes with 2,000 cells per dish. Each experiment also included positive and negative controls in the same number of dishes. Twenty-four hour cultures were exposed to the organics extract for 48 hours at which time the medium was removed, the cells were rinsed and fresh medium was added. Medium was changed twice weekly until the cells reached confluence and weekly after that. Six weeks after treatment, the cells were stained and examined for transformed foci.

Plating efficiency was determined by exposing 200 cells (five dishes per concentration) to the extract. Conditions were the same as in the transformation assay. At the end of ten days, the cells were stained and the colonies counted to determine the survival fraction. The transformation frequency was defined as the percentage of cells giving rise to Type II and Type III foci, corrected for plating efficiency, thus providing the number of foci formed per thousand surviving cells.

## ORGANIC PARAMETERS

### GENERAL DESCRIPTION

Many discrete trace organic compounds in water can be detected and quantified by one or more specific analytical techniques. However, it is currently estimated that up to ninety percent of the organic compounds in water have not been identified using available methods and analytical instrumentation. Therefore, a majority of the organics can only be detected by techniques which determine gross parameters, such as the amount of organically bound carbon (total organic carbon) and organically bound halogenated compounds (total organic halides).

Trace organics methods are listed in Table 4.2-5. A summary of each analysis is discussed in this section grouped by analytical instrumentation as follows:

#### Gas Chromatography/Electron Capture Detector

- Liquid-liquid extraction (LLE)
- Pesticides/PCBs
- Herbicides

#### Gas Chromatography/Mass Spectroscopy

- Volatile organics (VOA)



TABLE 4.2-5  
ORGANICS METHODS

Parameter <sup>1</sup>	Method	Reference
Acid extractables	Methylene chloride, GC/MS	EPA 625
Anion/cation	Resin adsorption, HPLC	Specialized analysis <sup>2</sup>
Base-neutral extractables	Methylene chloride, GC/MS	EPA 625
Closed-loop stripping	Purge-carbon trap, GC/MS	Specialized analysis
Dihaloacetoneitriles	Pentane extraction, GC/ECD	Specialized analysis
Herbicides	Methylene chloride, GC/ECD	Specialized analysis
HPLC	Methylene chloride, HPLC	Specialized analysis
High resolution GC/MS	Closed loop stripping extract	Specialized analysis
Pesticides/PCB	Methylene chloride, GC/ECD	EPA 608
Steam distillation	Distillation, GC/MS	Specialized analysis
Total organic carbon	Chemical-UV oxidation	EPA 415.1
Total organic halide	Carbon adsorption, oxidation, microcoulometric detection	TOX Joint Task Force Report, EPA 450.1
Trihalomethane formation potential	Pentane extraction, GC/ECD	EPA 510.1
Trihalomethanes	Pentane extraction, GC/ECD	EPA 501.2
Volatile organics	Purge and trap, GC/MS	EPA 624

1. Organics analyses were conducted at the off-site laboratory. THM and TOC analyses were also performed at the EEWTP.
2. Detailed description of specialized analysis protocols are given in Appendix A, Section 1.

## Analytical Methodology

- Base-neutral (BN) and acid extractables
- Closed-loop stripping (CLS)

### Surrogate Parameters

- TOC
- TOX

Complete protocols of all the trace organics methods are included in Appendix A, Section 1.

The plant monitoring program included herbicides, pesticides/PCBs, base-neutral extractables, acid extractables, CLS, VOA and LLE. Also during a six month period, twelve grab samples were analyzed using the following additional organics procedures: steam distillation, anion/cation fractions, HPLC, high resolution GC/MS and dihaloacetonitriles. For each of these additional analysis, two grab samples were collected from the EEWTP blend tank, final carbon column effluent, EEWTP finished water and from the three local MWA treatment plants. Detailed protocols, precision and accuracy data and results of additional organics procedures are discussed in Appendix J.

Detection limits for trace organics are given in Section 4 of this chapter (Table 4.4-2 and 4.4-3). Table 4.4-3 serves a dual purpose, in that, it also shows the analysis or, in many cases, the multiple analyses used to quantify a given compound. For example, dibromochloromethane was analyzed by LLE, VOA and CLS procedures. The three method detection limits for this compound are given in the dibromochloromethane row in the table whereas all the compounds analyzed by a particular method (LLE, VOA, CLS, etc.) can be determined by looking down the method column.

## GAS CHROMATOGRAPHY

The primary technique used to determine specific compounds in water was Gas Chromatography (GC). In this technique, a sample or sample concentrate was introduced onto a GC column in a gaseous phase. The column was coated with a thin layer of SE-54 which has some affinity towards the compounds of interest in the sample. The column and sample were heated while an inert gas was passed through the column, thereby causing the compounds in the sample to separate from each other. The degree of separation was based on several parameters, such as the boiling point of the specific compounds, the length of the column, and the type of liquid phase in the column. The type of columns used in this study are fused silica capillary columns. The specific columns used were 30 m in length with an inside diameter of 0.25 mm.

As the individual compounds eluted from the GC column they were detected by one of two detectors, either an electron capture detector (ECD) or a mass spectrometer (MS). The amount of signal produced by the detector was proportional to the amount of compound eluting from the GC column.

Compounds are identified by the GC according to the length of time it takes for the compound to elute from the column. This retention time depends on the

compound's boiling point, polarity, and other factors. If an unknown compound eluted at the same time as a known standard compound, then the unknown was tentatively identified as the standard. For the GC/MS analyses, there was an added degree of certainty to the identification based on the mass spectra of the compound.

Blanks were analyzed with each set of samples. These blanks were analyzed to assure that the amount of the compound determined was actually in the sample and not due to other factors, such as contaminated glassware, contaminated instruments, or contamination introduced due to transportation of the sample. System blanks, consisting of laboratory purified water, were analyzed to assess the contamination due to the first two sources. Travel blanks consisting of laboratory water sent to the treatment plant and back to the laboratory were used to assess the contamination due to transport.

The amount of a compound in a sample was determined by comparing the area of the peak produced by the compound as it passed through the detector to the area produced by a standard of known concentration.

### ANALYSIS BY GAS CHROMATOGRAPHY/ELECTRON CAPTURE DETECTOR

#### Principles

Analysis by Gas Chromatography/Electron Capture Detector (GC/ECD) involved the separation of the components of a sample by GC followed by detection in an electron capture detector (ECD). The ECD is a specific detector sensitive to compounds which contain electro-negative atoms (such as halogens) and not very sensitive to other types of compounds. This made it very useful for detecting specific halogenated compounds at low levels even when other compounds were present at much higher levels. The real utility of the ECD lies in the fact that many chemicals of health concern found in water are halogenated. The GC/ECD was used for the detection of dihaloacetoneitriles, halogen containing herbicides and pesticides, PCBs, THMs and chlorinated solvents.

#### Liquid-Liquid Extraction

The Liquid-Liquid Extraction technique (LLE) was used for the analysis of THMs and several other chlorinated solvents. The THMs detected were chloroform, dichlorobromomethane (DCBM), dibromochloromethane (DBCM), and bromoform. The chlorinated solvents detected were carbon tetrachloride, trichloroethene (TCE), and tetrachloroethene (PCE).

The LLE analysis consisted of a pentane extraction followed by GC/ECD analysis. Each sample was sent to the off-site laboratory headspace-free in a 125 ml amber glass bottle. For the extraction, 10 ml of sample were removed and 5 ml of buffer solution and 5 ml of pentane added. The pentane contained 1,2-Dibromopropane as an internal standard (1725 µg/L in pentane). After the samples were shaken for twenty minutes the sample bottles were opened and the pentane extract transferred to two 2 ml autosampler vials. The sample

extracts were placed in the autosampler of the GC along with the standards and blanks.

The LLE samples were quantified by the internal standard method. The standards were run every day at concentrations of 1.0, 5.0, 10, 20, 50, and 100 µg/L. Extraction blanks were also run with every set. In addition, approximately one out of ten samples was either run in duplicate or was spiked with the standard compounds.

#### Pesticides/PCBs

The analysis of pesticides and PCBs covered twenty-six solvent-extractable compounds. These particular pesticides were chosen on the basis of their occurrence data, health effects and their appearance in the EPA's priority pollutant list. The list of the pesticide and PCB compounds is presented in Table 4.4-3.

One liter of the sample was adjusted to pH 7 by adding sulfuric acid or sodium hydroxide and extracted with 60 ml of pesticide grade methylene chloride. The extraction was repeated a second and a third time in the same manner. The extracts were combined, poured through a column of acidified anhydrous sodium sulfate and evaporated to 1 ml at 60-65°C. After adding 50 ml of hexane, the sample was evaporated to 2 ml at 90°C. The final volume of the extract was diluted to 10 ml with hexane. The sample extract was placed in the autosampler of the Varian 4700 GC along with the standards and blanks.

The samples were quantified using the external standard technique because no suitable internal standard could be found. A series of eleven standards were run every quarter to demonstrate the linearity of the analysis. The concentrations extracted and analyzed were: 0.01, 0.05, 0.10, 0.15, 0.20, 0.25, 0.375, 0.50, 0.75, 1.0, and 1.25 µg/L. Each time a sample set was analyzed three concentrations of standards were run. The concentrations were; 0.10, 0.50, and 1.0 µg/L. An extraction blank was run with every set. In addition a spiked sample was run every tenth sample.

#### Herbicides

Selected herbicides were chosen due to their potential health significance and appearance in the EPA primary drinking water regulations. They were (2,4-Dichlorophenoxy)acetic acid, (also called 2,4-D); (2,4,5-Trichlorophenoxy)acetic acid, (also called 2,4,5-T); and 2-(2,4,5-Trichlorophenoxy)propionic acid, (also called 2,4,5-TP or Silvex).

The analysis of the herbicides consisted of a methylene chloride extraction followed by derivitization of the herbicides and subsequent GC/ECD analysis. An acidified 1L sample was extracted with 60 ml of pesticide grade methylene chloride. The extraction was repeated a second and a third time in the same manner. The three extracts were combined, hydrolyzed with 1N potassium hydroxide, and then heated for one hour at 80°C. The extract was acidified and extracted three times with 20 ml of methylene chloride. The

combined methylene chloride extract was poured through a column of acidified anhydrous sodium sulfate, collected and evaporated to approximately 5 ml. The extract was allowed to cool and 1 ml of toluene added. The extract was then evaporated to approximately 0.9 ml. Next, 0.5 ml of a fourteen percent boron trifluoride in methanol solution was added and the extract heated to 50°C for thirty minutes. After mixing 4.5 ml of a five percent sodium sulfate solution into the cooled extract, the top layer (toluene) was removed and passed through a micro-column containing 1.5 cm florisil and 2.5 cm acidified sodium sulfate. The sodium sulfate solution was extracted again with 1 ml of toluene and that extract passed through the micro-column. This was repeated until 5 ml of extract was collected. The samples were analyzed by GC/ECD on a Varian 4700 GC along with the standards and blanks.

The herbicide samples were quantified using the external standard method because no suitable internal standard could be found. The standard was spiked into clean water at 1.0 µg/L. This was then extracted as a normal sample. In addition, an extraction blank consisting of clean water was run. One standard and one blank were run per set of samples.

### ANALYSIS BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY

#### Principles

Analysis by Gas Chromatography/Mass Spectrometry (GC/MS) involved the separation of the components of a sample by GC followed by detection by a mass spectrometer (MS). The mass spectrometer detects compounds by fragmenting the molecules into charged fragments with a high energy electron beam and separating them by molecular weight using a quadrupole magnet in an electric field. The fragments leaving the quadrupole are detected on an electron multiplier. Most chemicals have unique fragmentation patterns called mass spectra. Compounds separated by the GC are identified by retention time and mass spectra. This is accomplished by performing a computerized search of the EPA/NBS library of 25,000 mass spectra and comparing them to the unknown spectra. The comparison program "fits" the unknown to each spectrum in the library, displaying the ten "best fits". The program returns the possible identifications with fit and purity values which are used by the MS operator to determine the quality of the identification.

In this study a Finnigan 4021 GC/MS was used for the analysis of many different compounds in several different methods. The methods included base-neutral and acid extractables, closed-loop stripping, steam distillation, and volatile organics.

#### Volatile Organic Analysis

The Volatile Organic Analysis (VOA) consisted of concentrating the sample with a Tekmar LSC-2 liquid sample concentrator by purging the volatile organics and trapping them on a Tenax trap. The organics were then desorbed from the trap and analyzed by the GC/MS. The 56 compounds quantified by this method are presented in Table 4.4-3.

The samples were quantified using the external standard method. Along with each set of samples, a 10 µg/L standard and a water blank were analyzed. The standard was used for all quantitation. Approximately one out of ten samples was either run in duplicate or spiked with 5 µg/L of the standard compounds. In addition, standard curves were analyzed to demonstrate that the instrument was linear in the range at which compounds were usually detected. The concentrations used were 1, 5, 10, 20, and 50 µg/L.

### Base-Neutral and Acid Extractables

The base-neutral (BN) and acid extractable analyses consisted of two solvent extractions followed by GC/MS analysis. Compounds quantified by BN and acid analyses along with their detection limits are listed in Table 4.4-3. Fifty-eight BN and seventeen acid extractable compounds were quantified.

One liter samples were adjusted to pH 11 by the addition of sodium hydroxide. This step facilitated the extraction of amines and other similar organics by neutralizing any positive ionic character. Next, 100 µl of an internal standard mixture was added to the sample. The sample was extracted with 60 ml of pesticide grade methylene chloride. The extraction was repeated a second and a third time in the same manner. The combined pH 11 extract was called the BN extract. The BN extract was then poured through a column of acidified anhydrous sodium sulfate and evaporated to 0.5 ml. The final volume of the extract was diluted to 1.0 ml.

If the sample was to be analyzed for acid extractables, the water previously used for the BN extraction (or a new sample) was adjusted to pH 1 with 6 N sulfuric acid. This step facilitated the extraction of organic acids and other similar organics by neutralizing any negative ionic character. It was again extracted with three 60 ml portions of methylene chloride. The combined pH 1 extract was called the acid extract. The acid extract was poured through a column of acidified anhydrous sodium sulfate and evaporated to 2 ml. The extract was then diluted to 4.0 ml and 2.0 ml saved in a glass vial with a TFE septa. This was called the unmethylated acid fraction. Several drops of mercury were added to the remaining 2.0 ml to remove the sulfur in the extract. Heptadecanoic acid was added to the extract as a check of the methylation reaction. Next, 1.5 ml of a previously prepared diazomethane methylation reaction mixture were added to the extract. The reaction mixture was prepared by the reaction of Diazald with potassium hydroxide followed by an ether distillation. After sitting for thirty minutes, the extract was blown down to 1.0 ml with a stream of nitrogen gas and saved in a glass vial with TFE septa. This was called the methylated acid extract. Methylation of the acid extracts was initiated on 1 December 1981.

The BN and acid extracts were injected separately or together on the GC/MS.

The samples were quantified using the external standard method. With each set of samples extracted, a water blank was extracted. In addition, approximately one out of ten samples were spiked with 20 µg/L of the standards as a quality

control measure. The samples were then injected into the GC/MS along with an injection of the standard (0.02  $\mu\text{g}/\mu\text{L}$ ).

#### Closed-Loop Stripping

The analysis of semi-volatile organics in water consisted of two parts: purging and concentration of the organics by the closed-loop stripping technique and the subsequent analysis by GC/MS. Forty-one semi-volatile organic compounds were quantified over a concentration range of approximately 0.001 to 1.0  $\mu\text{g}/\text{L}$ . Actual detection limits were dependent on the daily performance of the closed-loop stripping apparatus and the GC/MS system. Compounds quantified by CLS are listed along with their detection limits in Table 4.4-3.

For extraction, the sample (500 ml) was spiked with the internal standards (1-Chlorohexane, 1-Chlorodecane and 1-Bromo-4-fluorobenzene) to a concentration of 0.1  $\mu\text{g}/\text{L}$ . After purging the sample for one hour at 60°C, the trap was extracted twice with 10  $\mu\text{L}$  of carbon disulfide. The carbon disulfide extracts were analyzed by GC/MS as soon as possible after extraction. The extracts were stored at -18°C prior to analysis.

The CLS samples were quantified using the internal standard method. 1-Bromo-4-fluorobenzene was used for this purpose. A 0.1  $\mu\text{g}/\text{L}$  standard was stripped at the same time the samples were stripped and this was used as the standard for quantification. In addition, a system and a water blank were run with each set of samples. Approximately one out of every set of samples was either run in duplicate or spiked at 0.1  $\mu\text{g}/\text{L}$ .

#### SURROGATE PARAMETERS

In order to determine the total amount of organic material in the water surrogate parameters have been developed. These are total organic carbon (TOC) and total organic halides (TOX). TOC measures the total amount of organic carbon in the water, whether natural or manmade. The TOX analysis determines the amount of organically bound halogen present in the water. There is very little naturally occurring TOX; therefore, this analysis was a good indicator of the amount of manmade halogenated chemicals present in the water.

#### Total Organic Carbon

The TOC analysis utilized persulfate oxidation in the presence of ultraviolet light to convert the organic carbon in the sample to carbon dioxide. The carbon dioxide produced was quantitatively measured by an infrared analyzer specifically tuned to the absorptive wavelength of carbon dioxide. Inorganic carbon interference was removed by acidifying and purging the sample prior to analysis. An automated DC-80 TOC analyzer was used. Replicates of 10, 5, 3, 2 and 1 mg/L TOC standards and the reagent water blanks were placed before and after each set of samples. The TOC procedure had a method detection limit of 0.06 mg/L.

### Total Organic Halides

The TOX procedure consisted of adsorbing the organic compounds onto activated carbon, removing the inorganic halide interference and then pyrolyzing the carbon. The pyrolysis converts the organically bound halogens into halides. The halides were then swept to an electrolytic cell which detected the halides by microcoulometric titration with a silver electrode. The instrument used was the Xertex-Dohrmann DX-20 TOX analyzer.

The samples were quantified using the external standard method. Standards containing 100 µg/L TOX were analyzed at the beginning of each day to insure that the instrument was operating properly. In addition, carbon blanks were analyzed daily in order to evaluate the contribution to the TOX from the carbon. The TOX procedure had a method detection limit of 3.9 mg/L Cl<sup>-</sup>.

## MICROBIOLOGICAL PARAMETERS

### GENERAL DESCRIPTION

Bacteriological tests such as total coliforms, fecal coliforms and standard plate counts, were conducted at the on-site laboratory according to Standard Methods (Table 4.2-6). A high-volume modification of the Most Probable Number coliform assay was utilized at several plant process sampling locations and on all EEWTP and local MWA finished water samples allowing up to a 100-fold increase in assay sensitivity (see "Coliform Method Modifications", below).

Enteric virus, parasites, Salmonella and endotoxin assays were performed at the off-site laboratory. In the case of enteric viruses and parasites, large volume water samples were filtered from the process stream and then either the filter itself (parasites) or an organic concentrate of the filtered material (viruses) was shipped off-site for analysis. Water samples for the endotoxin and Salmonella assays were packed in ice and shipped directly to the off-site laboratory for immediate assay. These specialized analyses are discussed below. Detailed protocols are given in Appendix A, Section 1.

### COLIFORM METHOD MODIFICATIONS

Total and fecal coliforms were quantified by the Most Probable Number (MPN) method according to Standard Methods, 15th Edition (1980). At sampling sites where undetectable levels using the standard procedure were expected, a high-volume modified technique was employed to increase assay sensitivity. In this procedure, five 1,000 ml or five 100 ml portions were filtered through 0.45 µm sterile membrane filters. Each filter was aseptically placed in a single strength presumptive Lauryl Tryptose Broth (LTB) tube and transferred to confirmatory Brilliant Green Lactose Bile Broth (BGB) if growth developed in LTB after 24 to 48 hours incubation at 35° ± 0.5°C. Positive LTB tubes were simultaneously transferred to fecal coliform E.C. medium according to Standard Methods. All 10 ml and 1 ml aqueous sample portions were directly inoculated into LTB in order to compare the Standard Methods procedure to the



TABLE 4.2-6  
MICROBIOLOGICAL METHODS

Parameter	Method	Reference	Location
Coliform, total and fecal	MPN	APHA <sup>1</sup> 908	On-site
Endotoxin	Limulus lysate	Mallinckrodt	Off-site
Enteric virus	Cytopathogenic effect	APHA 913	Off-site
Parasites	Microscopic examination	EPA-600-9-79-001	Off-site
Salmonella	MPN	EPA-600-8-78-017	Off-site
Total plate count	Pour plate	APHA 907	On-site

1. APHA refers to Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980.

TABLE 4.2-7  
TOTAL AND FECAL COLIFORM MPN METHODS

Site	Method	Dilution/Concentration
Blue Plains Effluent	Standard Methods	10 <sup>-2</sup> , 10 <sup>-3</sup> , 10 <sup>-4</sup>
Potomac Estuary	Standard Methods	10 <sup>-1</sup> , 10 <sup>-2</sup> , 10 <sup>-3</sup>
Blend Tank Effluent	Standard Methods	10 <sup>-1</sup> , 10 <sup>-2</sup> , 10 <sup>-3</sup>
Gravity Filter Effluent	Modified MPN	100 ml, 10 ml, 1 ml
Final GAC Effluent	Modified MPN	100 ml, 10 ml, 1 ml
Post-Ozone Effluent	Modified MPN	1,000 ml
EEWTP Finished Water	Modified MPN	1,000 ml, 100 ml, 10 ml
WTP I Finished Water	Modified MPN	1,000 ml
WTP II Finished Water	Modified MPN	1,000 ml
WTP III Finished Water	Modified MPN	1,000 ml

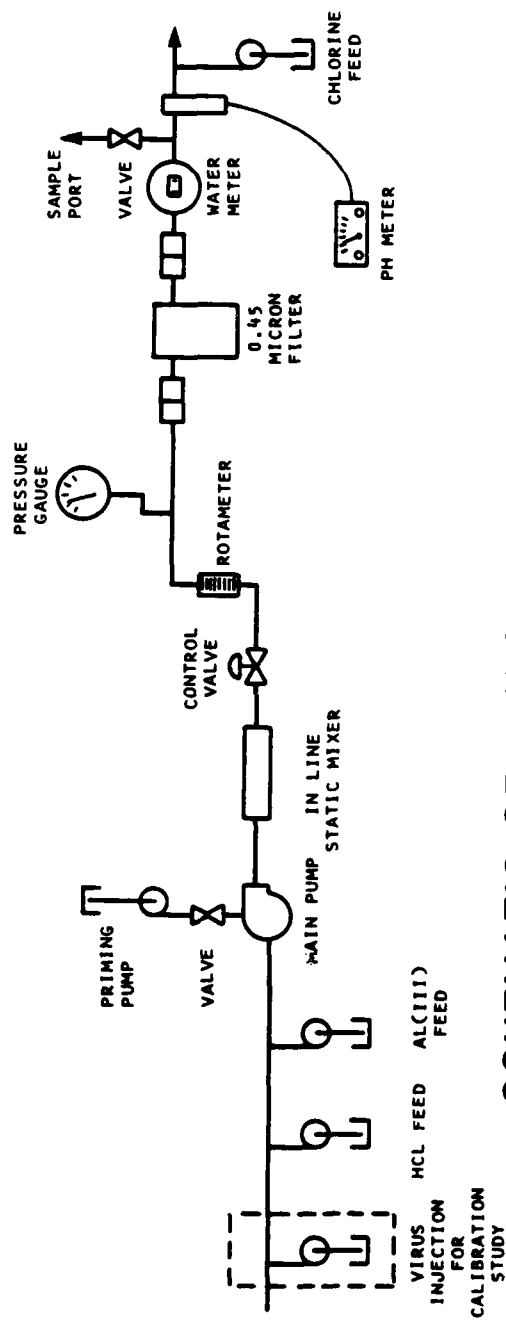
high-volume modification. Table 4.2-7 lists each sampling site and the dilution or concentration used on those samples. At various times it was necessary to change dilutions so that a quantifiable value could be determined.

The confirmed total coliform value, based on the number of positive BGB tubes, was calculated as the assay end point at all sampling locations from 16 March 1981 through 1 February 1983. WTP samples were quantified in the same manner as EEWTP samples using the three dilution, five tube MPN table. An assumption was made that 100 and 10 ml portions would have been negative for WTP samples. After 7 October 1982, the EEWTP and MWA finished water samples were processed one step further through the completed MPN test as a quality assurance procedure, as described in Standard Methods. The value derived from the completed assay is referred to as the verified total coliform concentration. The value derived directly from BGB tubes is referred to as the confirmed total coliform concentration. In the case when there were no positive BGB tubes from a finished water sample, the confirmed total coliform value of less than 0.02/100 ml was automatically recorded as the value for the completed test on that sample.

#### SPECIALIZED ANALYSES

##### Enteric Viruses

Virus Concentration. The virus concentration method is based on an adsorption/elution procedure described in the 15th edition of Standard Methods. Water was pumped through a concentrator consisting of a sample pump, in-line alum, acid and sodium thiosulfate chemical feed pump and filter housing. A schematic and photograph of the concentrator is presented in Figure 4.2-2. The chemical feed adjusted the sample to pH 3.5 with diluted hydrochloric acid and Al(III) was added to obtain a final concentration of 0.005M for EEWTP influents and 0.0005M for finished water sites. Up to 1,000 gallons were concentrated at



SCHEMATIC OF VIRUS CONCENTRATOR  
FIGURE 4. 2-2



## Analytical Methodology

the finished water sites. Fewer gallons were concentrated at the EEWTP influent sites because of filter clogging due to suspended solids.

**Elution.** The sorbed viruses were eluted twice with one liter of one percent beef extract/0.4 percent glycine solution at pH 9.0. Elution was conducted on-site immediately following the concentration run. Each filter was initially eluted in a co-current manner to elute the bulk of the non-solids-associated viruses. The filter was re-eluted in a counter-current manner to remove the eluted solids-associated viruses. The concentrate was then transported to the off-site laboratory for reconcentration and assay.

**Reconcentration.** The eluate was further reduced in volume by an organic flocculation technique (Katzenelson, 1976) at pH 3.5. The resulting pellet was resuspended in approximately 30 ml of 0.15 M sodium phosphate buffer, pH 9.0, and treated with antibiotics, in order to reduce bacterial contamination. Each concentrate was shaken for fifteen minutes with an equal volume of chloroform to reduce non-specific toxicity. The residual chloroform was removed by bubbling sterile filtered nitrogen through the sample for thirty minutes. The sample was stored at -70°C until assayed.

**Virus Assay.** The MPN method was used to enumerate the enteric viruses in the sample concentrates. In this method a gradual and progressive destruction of cells occurs upon viral infection of the cell monolayers. The viruses multiply within the cells producing some observable change in cell morphology. These cellular changes which are evidence of a viral infection are referred to as cytopathic effects (CPE).

The sample concentrates were assayed for viruses by inoculating a portion of the concentrates onto two different cell culture lines: 1) BGM, a continuous cell line derived from the Buffalo Green Monkey kidney; and 2) MA-104, a continuous Rhesus Monkey kidney cell line. Many enteroviruses are capable of infecting at least one of these cell lines. RD cells were initially used during the first several months of monitoring until replaced with MA-104.

Approximately one-half of the concentrate (2 to 5 ml) was assayed on BGM and MA-104 cells growing in liquid culture flasks. At the end of the fourteen-day incubation period, all flasks were blind passed into tubes with fresh cells. These tubes were incubated at 35°C on a roller apparatus and scored for CPE. A second blind passage of the positive tubes was made after the fourteen-day incubation period. A positive isolation was one which produced typical viral CPE in the second passage.

The proportion of CPE positive and negative tubes is statistically related to the probable number of viruses in the concentrate. The MPN cytopathogenic units (MPNCU) were calculated according to the following formula:

## Analytical Methodology

$$D = -1/V \ln (S/N)$$

where: D = the MPNCU/ml concentrate  
V = the total volume of sample inoculated in ml  
S = the number of CPE negative tubes  
N = the number of tubes inoculated

The value obtained for D and the volume concentrated were used to back calculate the MPNCU/gal.

Virus Isolate Identification. Enterovirus isolates were identified using Lim Benyesh-Melnick dehydrated antisera pools. The eight antisera pools were designed in such a manner that a given antiserum appears in one, two or three pools. Thus, an unknown enterovirus can be identified if it is neutralized by the pool or pools containing its homotypic antiserum.

### Parasites

Sample Collection. The same apparatus in Figure 4.2-2 was used to concentrate parasites from up to 500 gallon samples. Unlike the virus concentration, no additional chemicals were added to the sample prior to filtration. Parasites were concentrated on an orlon fiber filter wound on a polypropylene support. After sampling, the filters were dipped in a ten percent Formalin preservative solution and then shipped to the off-site laboratory in polypropylene zip-lock bags.

Sampling Processing. The entire filter was unwound and the parasites were removed by soaking and kneading the fibers in distilled water until the fibers appeared clean. The resulting suspensions were centrifuged several times producing a pellet containing parasite organisms. The protocol is outlined in Appendix A, Section 1.

Parasite Concentration. A zinc sulfate ( $ZnSO_4$ ) flotation technique was utilized to separate the parasitic components in the pellet material from excess debris through differences in specific gravity. Protozoan cysts and certain helminth eggs float to the top of the centrifuged  $ZnSO_4$  solution and are recovered in the surface film while the debris settles to the bottom.

Staining and Identification. The surface film was stained with Lugol's or D'Antonio's iodine stain and then examined microscopically for Giardia cysts, Entamoeba histolytica, Acanthamoeba, Naegleria gruberi cysts, Ascaris eggs, Hookworm eggs and Trichuris trichiura eggs. The presense of unidentified larval worms was also recorded.

### Salmonella

A five-tube MPN procedure was used for quantitating Salmonella sp. in water. The enrichment, isolation and primary biochemical test methods are found in Microbiological Methods for Monitoring the Environment (EPA-600-8-78-017).

## Analytical Methodology

Dulcitol-selenite broth was prepared for the enrichment step in which direct aqueous samples or membrane filters were inoculated into five, 50 ml portions of media, as described for the high-volume coliform test modification. Positive presumptive tubes (turbidity, selenite reduction) after 24 to 72 hours incubation at 35°C were streaked onto xylose lysine desoxycholate (XLD) agar. Black-centered red colonies on XLD, typical of Salmonella and Arizona organisms, were purified on fresh XLD plates and then identified by biochemical screening in triple sugar iron agar, urea agar and lysine iron agar.

### Endotoxin

Endotoxins are lipopolysaccharides from the outer cell wall of heterotrophic, gram negative bacteria and Cyanobacteria (blue green algae). They are detected and quantified by the coagulation of aqueous Limulus amoebocyte extract in the presence of lipopolysaccharides. The endotoxin activates an enzyme in the Limulus amoebocyte lysate reagent (LAL) which then reacts with a low-molecular-weight clottable protein to form a gel.

The LAL and standard E. coli endotoxin were purchased as a kit from Mallinckrodt, Inc. The gel-extinction endpoint assay as described in the manufacturer's instructions was followed. The assay was sensitive enough to determine 0.006 ng/ml.

### SECTION 3

#### PRECISION AND ACCURACY

Precision and accuracy data were developed for most of the procedures and instrumentation. The approach used for precision and accuracy was obtained from a combination of two documents: Handbook for Analytical Quality Control in Water and Wastewater Laboratories, Environmental Protection Agency, 1979 and "Guidelines for Data Acquisition and Data Quality Evaluation in Environmental Chemistry," Analytical Chemistry 52:2242-2249, 1980. Precision and accuracy data continued to be developed throughout the course of the project for certain parameters which had not received specific prior attention (most notably, certain organics).

#### PRECISION

Precision refers to the reproducibility of a method when it is repeated on a homogeneous sample under controlled conditions, regardless of whether or not the observed values are widely displaced from the true value. It is expressed as the standard deviation or coefficient of variation among seven replicate analyses run on a single, homogeneous sample. Project precision tables are in Appendix A, Section 2. In addition, quality control data obtained during the course of the project were used to monitor day-to-day precision for duplicate determinations at levels observed at the EEWTP.

#### ACCURACY

Accuracy is defined as the difference between the measured value and the true value when the latter is known or assumed. Relative error expresses this difference as a percentage of the actual amount. It is possible to determine accuracy only when a standard substance is available that can be added to a sample in a known quantity from which percentage recovery can be based. Accuracy tables are found in Appendix A, Section 2.

## SECTION 4

### DETECTION LIMITS

Two types of detection limits were calculated. The "method detection limit" (MDL) was used for inorganic and organic parameters. The "instrument detection limit" (IDL), was determined for organic parameters analyzed by gas chromatography or gas chromatography/mass spectroscopy.

#### INSTRUMENT DETECTION LIMIT

The IDL is the minimum concentration above which an analyst can detect and identify a compound. For purposes of demonstrating method development and documenting known detections of compounds from retention time, mass spectra and peak shape data, organics analysts prefer to report and identify compounds above the IDL. The IDL is defined as the concentration which corresponds to an instrument signal approximately equal to two times the electronic and sample noise levels. If the concentration of a compound was below the MDL for the method (see following section), then the compound was reported as "Not Quantifiable" (NQ). Compounds with sample concentrations below the IDL were reported as "Not Detected" (ND).

#### METHOD DETECTION LIMIT

The MDL (also called the minimum quantification limit), as used here, is defined as three times the standard deviation of a set of seven replicates of a standard at a concentration no more than five to ten times the IDL. The MDL is the minimum concentration of a substance that can be identified, measured and reported with 99 percent confidence that the concentration is greater than zero. For inorganic compounds, this was the only detection limit utilized and values below the MDL were reported as ND.

#### UPPER AND LOWER QUANTIFICATION LIMITS

Total coliforms, fecal coliforms, Salmonella and enteric virus MPN assays have upper and lower quantification limits which are not based on the detection limit concept as described above. The limits are a result of the quantification range inherent in the use of the MPN formula for enteric viruses or the MPN bacteriological table found in Standard Methods. The MPN table is based on the positive tube combinations in a three dilution, five tube assay using 10, 1 and 0.1 ml sample aliquots per tube. Five negative confirmed tubes and five positive tubes at each of these dilutions give quantification limits of <2/100 ml and >2,400/100 ml of sample, respectively. If 1, 0.1 and 0.01 ml per tube are inoculated, ten times the value from the table is recorded and the quantification limits are accordingly ten times greater. If 1,000 ml portions are inoculated in a manner described for the high-volume coliform technique, the sensitivity of the assay is increased by 100 times, resulting in quantification



## Detection Limits

limits of  $<0.02/100$  ml and  $\geq 24/100$  ml. A possible combination of positive tubes exists which results in a coliform level of  $1.8/100$  ml. This occurs when the 10 and 0.1 ml tubes are negative and the middle dilution, 1 ml, has one positive out of five tubes. This condition occurred in several of the project samples. Therefore, the lower quantification limit for coliforms was set at  $1.8/100$  ml or 10-fold intervals depending on the dilution range of the sample.

## SUMMARY

Detection limits for project inorganic and organic parameters are listed in Table 4.4-1 to 4.4-3.

# Detection Limits

TABLE 4.4-1

## INORGANICS DETECTION LIMITS

	Method Detection Limit
<b>PHYSICAL/AESTHETIC</b>	
Dissolved Oxygen	0.15 mg/L
Temperature	-15°C (IDL)
pH	0.1 units
Turbidity	0.05 NTU
Total Suspended Solids	3.6 mg/L
Color	3.0 color units
MBAS	0.03 mg/L
Taste	2.0 taste units
Odor	1.0 TON
Free/Total Chlorine	0.1 mg/L-Cl
Ozone Residual	0.1 mg/L
<b>MAJOR CATIONS, ANIONS AND NUTRIENTS</b>	
TDS by drying	10.0 mg/L
TDS by addition	1.0 mg/L
Electroconductivity	0.1 umho/cm
Calcium	0.2 mg/L
Hardness (Ca + Mg)	1.0 mg/L-CaCO <sub>3</sub>
Hardness (titration)	2.0 mg/L-CaCO <sub>3</sub>
Magnesium	0.1 mg/L
Potassium	0.3 mg/L
Sodium	0.1 mg/L
Alkalinity	2.7 mg/L-CaCO <sub>3</sub>
Bromide	0.003 mg/L
Chloride	0.1 mg/L
Cyanide, Total	0.005 mg/L
Fluoride	0.1 mg/L
Iodide	0.002 mg/L
Nitrogen, Nitrate + Nitrite	0.02 mg/L
Nitrogen, Ammonia	0.02 mg/L
Nitrogen, Total Kjeldahl	0.2 mg/L
Ortho Phosphate	0.01 mg/L
Silica	0.2 mg/L
Sulfate	0.6 mg/L
<b>METALS (All values in mg/L)</b>	
Aluminum ICAP	0.003
Antimony furnace AAS	0.0003
Arsenic furnace AAS	0.0002

# Detection Limits

TABLE 4.4-1 (Continued)

## INORGANICS DETECTION LIMITS

	Method Detection Limit
METALS (Continued, All values in mg/L)	
Barium ICAP	0.002
Beryllium ICAP	0.0008
Boron ICAP	0.004
Cadmium ICAP	0.0008
Cadmium furnace AAS	0.0002
Chromium ICAP	0.003
Chromium furnace AAS	0.0002
Cobalt ICAP	0.003
Cobalt furnace AAS	0.0001
Copper ICAP	0.0008
Copper flame AAS	0.0012
Iron ICAP	0.003
Lead furnace AAS	0.0003
Lithium ICAP	0.001
Lithium flame AAS	0.0004
Manganese ICAP	0.001
Mercury cold vapor	0.0003
Molybdenum ICAP	0.002
Nickel ICAP	0.001
Selenium furnace AAS	0.0002
Silver flame AAS	0.0008
Silver furnace AAS	0.0002
Thallium furnace AAS	0.0009
Tin ICAP	0.004
Titanium ICAP	0.002
Vanadium ICAP	0.002
Zinc ICAP	0.002
Zinc flame AAS	0.0012
RADIATION (All values in pCi/L)	
Gross Alpha	0.1
Gross Beta	0.1
Radium	0.1
Strontium-90	0.2
Tritium	1,000

## Detection Limits

TABLE 4.4-2  
ORGANIC PARAMETERS  
INSTRUMENT DETECTION LIMITS

Analysis	Range ( $\mu\text{g/L}$ )	Exceptions
Liquid-liquid extraction	0.1	Dichloriodomethane (0.5 $\mu\text{g/L}$ )
Pesticides	0.01	
PCBs	0.1-0.2	
Herbicides	0.1	
VOA	0.1-0.5	
Base/neutral extractables	0.1-5.0	Benzidine (50 $\mu\text{g/L}$ ) Tricresol phosphate (50 $\mu\text{g/L}$ ) Dioxin (10 $\mu\text{g/L}$ )
Acid extractables	1.0-5.0	2-Methyl-4,6-dinitrophenol (10 $\mu\text{g/L}$ )
CLS	0.0005-0.01	Toluene (0.02 $\mu\text{g/L}$ )

# Detection Limits

TABLE 4.4-3

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in $\mu\text{g/L}$ )

### HALOGENATED ALKANES

	<u>LLE</u> <sup>1</sup>	<u>VOA</u> <sup>2</sup>	<u>BN</u> <sup>3</sup>	<u>CLS</u> <sup>4</sup>
<b>Trihalomethanes</b>				
Bromoform	0.2	0.6		0.04
Chloroform	0.3	0.2		
Dibromochloromethane	0.2	0.4		0.05
Dichlorobromoemethane	0.3	0.2		0.07
Dichloriodomethane	0.5	(1.0) <sup>5</sup>		
Total THMs	0.2			
<b>Halogenated Methanes (other than THMs)</b>				
Bromochloromethane		0.6		
Bromomethane		0.3		
Carbon tetrachloride	0.2	0.5		
Chloromethane		0.4		
Dichlorodifluormethane		(1.0)		
Dichloromethane		2.0		
Iodoform		(1.0)		
Trichlorofluoromethane		0.4		
<b>Halogenated Ethanes</b>				
Chloroethane		0.2		
1,2-Dibromoethane		0.1		0.05
1,1-Dichloroethane		0.6		
1,2-Dichloroethane		0.4		
Hexachloroethane		(1.0)	7.5	0.05
1,1,2,2-Tetrachloroethane		0.2		0.05
1,1,1-Trichloroethane		0.2		
1,1,2-Trichloroethane		0.1		0.07
<b>Halogenated Alkanes (C3 or greater)</b>				
1,2-Dibromo-3-chloropropane		0.2		
1,2-Dichloropropane		0.2		0.08

1. LLE = Liquid-liquid extraction

2. VOA = Volatile organics analysis

3. BN = Base/neutral extractables

4. CLS = Closed-loop stripping

5. ( ) = No P/A data available, MDL estimated value from 10x the IDL

# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in µg/L)

### HALOGENATED ALKENES

	<u>LLE</u>	<u>VOA</u>	<u>BN</u>	<u>CLS</u>
<b>Halogenated Ethenes</b>				
Chloroethene (vinyl chloride)		0.2		
1,1-Dichloroethene		0.5		
Cis-1,2-dichloroethene		(1.0) <sup>a</sup>		
Trans-1,2-dichloroethene		0.5		
Tetrachloroethene	0.4	0.5		0.02
Trichloroethene	0.3	0.7		0.1
<b>Halogenated Alkenes (C3 or greater)</b>				
Cis-1,2-dichloropropene		(1.0)		
Cis-1,3-dichloropropene		0.1		
Trans-1,3-dichloropropene		0.2		
Hexachlorobutadiene		(10.0)	12.0	0.05

a. ( )=No P/A data available, MDL estimated value from 10x the IDL.

# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in µg/L)

### AROMATIC HYDROCARBONS (Non-Halogenated)

	<u>VOA<sup>1</sup></u>	<u>BN<sup>2</sup></u>	<u>AC<sup>3</sup></u>	<u>MAC<sup>4</sup></u>	<u>CLS<sup>5</sup></u>
<b>Alkylbenzenes</b>					
Benzene	0.1				
Ethenylbenzene	(1.0) <sup>6</sup>				
Ethylbenzene	0.1				0.04
Propylbenzene	0.3				0.01
Toluene	0.1				0.09
Ortho-xylene (1,2-)	0.1				0.03
Meta-xylene and Para-xylene (1,3- and 1,4-)	0.4				0.04
<b>Nitrobenzenes</b>					
Nitrobenzene		2.0			
1-Methyl-2,4-dinitrobenzene		(10.0)			
1-Methyl-2,6-dinitrobenzene		10.0			
<b>Phthalates</b>					
Benzylbutylphthalate		7.0			
Bis(2-ethylhexyl)phthalate		8.0			
Di-n-butylphthalate		9.0			
Dicyclohexylphthalate		(50.0)			
Diethylphthalate		9.0			
Diisobutylphthalate		(50.0)			
Dimethylphthalate		10.0			
Diocetylphthalate		8.0			
Diphenylphthalate		(50.0)			
<b>Phenols</b>					
Phenol		5.0		8.0	
2,4-Dimethylphenol		(50.0)		(50.0)	
2,4-Dinitrophenol		(50.0)		(50.0)	
2-Methyl-4,6-dinitrophenol		(100.0)		(100.0)	
2-Nitrophenol		(50.0)		10.0	
4-Nitrophenol		(50.0)		8.0	

# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in $\mu\text{g/L}$ )

### AROMATIC HYDROCARBONS (Non-Halogenated)

	<u>VOA</u> <sup>1</sup>	<u>BN</u> <sup>2</sup>	<u>AC</u> <sup>3</sup>	<u>MAC</u> <sup>4</sup>	<u>CLS</u> <sup>5</sup>
<b>Naphthalenes</b>					
Acenaphthene		3.0			0.1
Acenaphthylene		2.0			
Naphthalene	0.5	2.0			0.04
<b>Other Multiring Aromatics</b>					
Anthracene		6.0			0.09
Benzidine		(500.0)			
Benzo(a)anthracene		7.0			
Benzo(b)fluoranthene		10.0			
Benzo(k)fluoranthene		10.0			
Benzo(g,h,i)perylene		20.0			
Benzo(a)pyrene		10.0			
Chrysene		6.0			
Dibenzo(ah)anthracene		9.0			
3,3'-Dichlorobenzidine		8.0			
1,2-Diphenylhydrazine		7.0			0.1
Fluoranthene		5.0			
Fluorene		3.0			0.08
Ideno(1,2,3-cd)pyrene		30.0			
Phenathrene		5.0			0.01
Pyrene		5.0			

1. VOA = Volatile organics analysis

2. BN = Base/neutral extractables

3. AC = Acid extractables without methylation

4. MAC = Acid extractables with methylation

5. CLS = Closed-loop stripping

6. ( ) = No P/A data available, MDL estimated value from 10x the IDL



# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in µg/L)

### HALOGENATED AROMATICS

	<u>VOA</u>	<u>BN</u>	<u>AC</u>	<u>MAC</u>	<u>CLS</u>
<b>Halogenated Benzenes</b>					
Bromobenzene	(1.0) a		4.0		
Chlorobenzene	0.2				0.02
4-Chloro-1-methylbenzene	0.2				0.02
1,2-Dichlorobenzene	0.2	4.0			0.02
1,3-Dichlorobenzene	0.2	4.0			0.02
1,4-Dichlorobenzene	0.2	6.0			0.02
Hexachlorobenzene		2.0			0.05
1-Chloro-2-nitrobenzene		(50.0)			
1-Chloro-3-nitrobenzene		(50.0)			
1-Chloro-4-nitrobenzene		(50.0)			
1,2,3-Trichlorobenzene	0.2				0.03
1,2,4-Trichlorobenzene	0.5	8.0			0.02
1,3,5-Trichlorobenzene	0.5				0.02
<b>Halogenated Phenols</b>					
2-Chlorophenol			5.0	8.0	
2-Chloro-3-methylphenol			(50.0)	(50.0)	
3-Chlorophenol			4.0	(10.0)	
4-Chlorophenol			(50.0)	9.0	
4-Chloro-3-methylphenol			5.0	7.0	
2,4-Dichlorophenol			6.0	7.0	
Pentachlorophenol			30.0	4.0	
2,3,5-Trichlorophenol			8.0	7.0	
2,3,6-Trichlorophenol			7.0	8.0	
2,4,5-Trichlorophenol			6.0	8.0	
2,4,6-Trichlorophenol			7.0	7.0	
<b>Halogenated Naphthalenes</b>					
1-Chloronaphthalene	(5.0)	2.0			0.05
2-Chloronaphthalene	(5.0)	9.0			0.05

a. ( ) = No P/A data available, MDL estimated value from 10x the IDL

# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in µg/L)

### PESTICIDES/HERBICIDES/PCBs

	<u>Pest</u> <sup>1</sup>	<u>Herb</u> <sup>2</sup>	<u>BN</u>	<u>CLS</u>
<b>Pesticides</b>				
Aldrin	0.1			
Atrazine			9.0	
Alpha-BHC	0.2			
Beta-BHC	0.2			
Delta-BHC	0.03			
Gamma-BHC (lindane)	0.02			
Chlordane	(0.1) <sup>3</sup>			
4,4'-DDD	0.1			
4,4'-DDE	1.0			
4,4'-DDT	0.09			
Dieldrin	0.1			
Endrin	0.07			
Endosulfan I	0.03			
Endosulfan II	0.03			
Endosulfan sulfate	0.02			
Heptachlor	0.2			
Heptachlor epoxide	0.1			
Hexachloropentadiene			20.0	0.03
Kepone	2.0			
Methoxychlor	0.09			
Toxaphene	(0.1)			
Dioxin			(100.0)	
Tricresolphosphate			(500.0)	
<b>Herbicides</b>				
2,4-D		0.1		
2,4,5-T		0.3		
Silvex (2,4,5-TP)		0.5		
<b>PCBs</b>				
Arochlor 1016	0.4			
Arochlor 1221	0.4			
Arochlor 1232	0.4			
Arochlor 1242	0.4			
Arochlor 1248	0.4			
Arochlor 1254	0.4			
Arochlor 1260	0.4			

1. Pest = Pesticides/PCBs

2. Herb = Herbicides

3. ( ) = No P/A data available, MDL estimated value from 10x the IDL

# Detection Limits

TABLE 4.4-3 (Continued)

## PRIMARY ORGANICS METHOD DETECTION LIMITS (All Values in µg/L)

### MISCELLANEOUS

	<u>VOA</u>	<u>BN</u>	<u>CLS</u>
<b>Amines</b>			
N-Nitrosodimethylamine		10.0	
N-Nitrosodiphenylamine		5.0	
N-Nitrosodipropylamine		3.0	
<b>Halogenated Ethers</b>			
1-Bromo-4-phenoxybenzene		5.0	0.03
1-Chloro-4-phenoxybenzene		8.0	0.03
2-Chloroethylvinylether	(1.0) <sup>a</sup>	(10.0)	
1,1'-(Methylenebis(oxy))bis-2-chloroethane		3.0	
1,1'-Oxybis(2-chloroethane)		4.0	0.08
2,2'-Oxybis(2-chloropropane)		3.0	
<b>Heterocyclic Compounds</b>			
Tetrahydrofuran	0.2		
<b>Ketones</b>			
Acetone	0.5		
2-Butanone	1.0		
Isophorone		3.0	
<b>Natural Odor Producing Compounds</b>			
Geosmin			0.05
Methylisoborneol			0.04

a. ( ) = No P/A data available, MDL estimated value from 10x the IDL

## SECTION 5

### SAMPLE COLLECTION, PRESERVATION AND SHIPMENT

#### SAMPLING METHODS

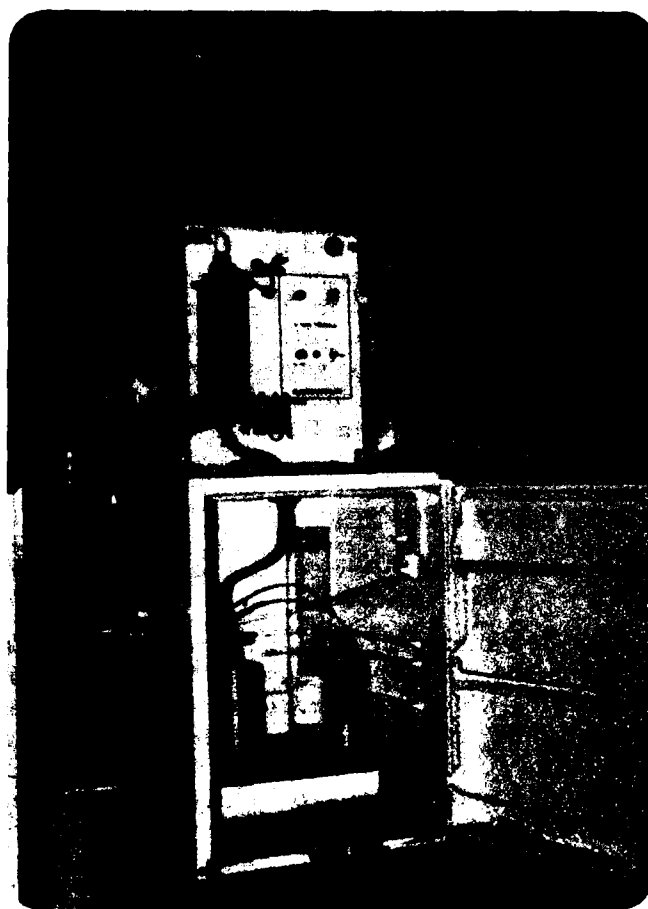
Three major sampling techniques were used during the project: composites, grabs and large volume concentrations. The most frequently used method, compositing, was chosen so that the samples represented an "average" water quality determined over a 24 to 72-hour operational period in which a constant volume was collected at hourly intervals and mixed together. This procedure was accomplished by using an automated sampling system. Automatic compositing was used only for those parameters which would not deteriorate in the samplers during the compositing period. Manual grab samples were taken when composites were not feasible, as in the cases of microbiological samples, disinfectant residual, temperature, pH, dissolved oxygen and total suspended solids. Large volume concentrations were necessary for enteric virus, parasites and toxicological assays, as described in Section 2. Sampling methods and monitoring frequencies are given in Chapter 3, "Plant Monitoring Programs", for each parameter.

#### AUTOMATIC COMPOSITE SAMPLING

##### Composite Samplers

Temperature controlled automatic composite samplers (ACSs) were installed at sampling locations in the EEWTP and local MWA water treatment plants. The ACSs provided samples which were sufficient in quantity and quality to meet analytical, preservation and handling requirements. During compositing, collection bottles were stored at 4°C in a refrigerator attached to the sampler. ACSs were programmed to sample 60 to 70 ml each hour for 24 hours. An ACS is shown in the accompanying photograph.

Inorganics. Inorganics were sampled into large volume plastic bottles by means of automatic samplers. These samplers operate by means of vacuum pumps/compressors which purge sample lines and draw up a sample at regular intervals. Where installed below the hydraulic grade line, the units sampled out of a continually bypassed flow stream which went to drain. This occurred only at the EEWTP influent locations (prior to flow measurement) and at the blend tank, where a minimal quantity of measured flow (2 to 3 gpm) was wasted. "Flow-through" units were also provided at the local water treatment plant locations. Metals and radiation samples were composited in plastic bottles by means of solenoids and time controls regulating the flow from the sample line to the refrigerator. All plastic bottles were rinsed with Milli-Q water after aliquoting and before being returned to the ACS.



**AUTOMATIC COMPOSITE SAMPLER**

## Sample Collection, Preservation and Shipment

**Volatile Organics.** Volatile organics (TOC, TOX, LLE, VOA and CLS analyses), taste and odor samples all required containers with no headspace above the liquid. "No-headspace" cylinders were fabricated for the EEWTP on the basis of a design developed by Westrick and Cummins, 1979. The design consisted of modified two liter graduated cylinders fitted with hollowed out and carefully machined teflon floats. Sample flow entered the bottom of the cylinder through a glass inlet/outlet tube with stopcock. The cylinders were installed in the refrigerator units. At hourly intervals by means of an electrically operated solenoid valve, a sample was diverted to the cylinders from a continuously flowing bypassed sample stream. In clear wells where the process water was below the ground floor grade, it was necessary to install gear pumps (of stainless steel and teflon construction) to obtain a sample flow stream.

Cylinders were rinsed with Milli-Q water after aliquoting and before being returned to the ACS. Each cylinder was designated for use at only one sampling site to avoid the possibility of cross-contamination. Because of the size and fragility of the cylinders, on-site personnel were unable to routinely muffle the cylinders.

**Synthetic Organic Compounds (SOCs).** From 16 March 1981 to 1 December 1981 SOC samples, including pesticides, herbicides, base-neutral extractables, acid extractables and PCBs, were collected by the automatic composite samplers over a three day period into one "no-headspace" cylinder at each site. Approximately 1,335 ml were manually aliquoted from the ACS cylinder each day into a two liter amber bottle. Therefore, each SOC sample shipped to the off-site laboratory consisted of two, two liter bottles from which all of the above parameters was analyzed. After 1 December 1981 each of the above SOC groups was sampled by the ACS individually into separate amber bottles (with headspace) over a 24-hour period.

### Sample Acceptance Criteria

Composite samples were shipped to the off-site laboratory if the following criteria were met:

1. At least 1,000 ml were sampled in 24 hours.
2. No chlorine residual was present in organics samples.
3. pH of cyanide (greater than 11), metals (less than 2) and radiation (less than 2) samples was properly maintained during compositing.

At the EEWTP, plant operators recorded ACS volumes every four hours. Samples with final composite volumes of less than 1,000 ml were accepted for analysis if the operators' records indicated constant operation of the ACS but at a reduced flow rate. Off-site samples with less than 1,000 ml were rejected because no additional information was available for ACS operation during the sampling period.

## Sample Collection, Preservation and Shipment

### Sample Aliquoting

In most cases, the composited samples in plastic bottles and no-headspace cylinders were aliquoted at the EEWTP into smaller "aliquot bottles" which were then shipped off-site for analysis. After 1 December 1981 all SOC amber glass collection bottles also served as the aliquot bottle.

### Composite Sample Preservation and Shipping

Details of composite sample preservation are presented in Table 4.5-1. After 1 December 1981, the sample collection bottles for acid extractables, base-neutral extractables, herbicides and pesticides/PCBs were shipped off-site. Therefore, they were also the "aliquot bottles" referred to in the last column of Table 4.5-1. In this case, the preservatives noted in the aliquot bottle column were added directly into the filled sample collection bottle, prior to shipment. For all other parameters, the collection bottle or cylinder contents were transferred to a different container, called the aliquot bottle, which was then shipped off-site for analysis. Preservatives were added to collection bottles and cylinders prior to composite sampling. Additional preservatives were added to aliquot bottles prior to aliquoting, with the exception of previously mentioned SOC's.

Each organics composite sample collected at sites after chlorination was tested amperometrically to assure the absence of a free chlorine residual. Any sample registering a free residual was discarded. The pH of each composite sample preserved with acid or base was checked to assure proper preservation.

Samples were shipped in specially constructed foam inserts which fitted into commercially available ice coolers. Cooler transit time did not exceed 24 hours.

### GRAB SAMPLING

Analyses were conducted on grab samples by plant operators as part of the Operational Data Collection System. These included pH, temperature, turbidity, dissolved oxygen, electroconductivity and chlorine residual. Other analyses conducted on grab samples included total coliforms, fecal coliforms, endotoxin, total bacterial plate count, Salmonella and total suspended solids. Grab samples were also routinely used to supplement composite monitoring information for total organic carbon. Grabs were taken from continuous flowing sample taps at each site. Free chlorine in bacteriological samples was neutralized by addition of sodium thiosulfate to collection bottles.

### CONCENTRATIONS

Large volume water samples were concentrated for enteric viruses, parasites, Ames test and mammalian cell transformation assays. These methods are described in Section 2.

TABLE 4.5-1  
SUMMARY OF COMPOSITE SAMPLE PRESERVATION

Sample Constituents	Sample Collection <sup>1</sup> Bottle	Amount of Preservative Added	
		"No-Headspace" <sup>1</sup> Collection Cylinder	Aliquot Bottle
Anions/MBAS	None	- - -	None
Asbestos	None	- - -	None
Cyanide	5.0 ml 6N NaOH	- - -	None
Metals	3.0 ml HNO <sub>3</sub> (conc)	- - -	None
Nutrients	None	- - -	0.1 ml H <sub>2</sub> SO <sub>4</sub> (conc)/125 ml
Odor	- - -	None	None
Radiation	3.0 ml HNO <sub>3</sub> (conc)	- - -	None
Acid extractables	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	- - -	1.5 ml H <sub>2</sub> SO <sub>4</sub> (conc)/L
Base/neutral extractables	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	- - -	1.5 ml, 5% HgCl <sub>2</sub> /L
Closed-loop stripping	- - -	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	1.0 ml, 5% HgCl <sub>2</sub> /L
Herbicides	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	- - -	1.5 ml H <sub>2</sub> SO <sub>4</sub> (conc)/L
Pesticides/PCB	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	- - -	None
Purgeable volatiles	- - -	1.5 ml, 1.2 M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	0.25 ml, 5% HgCl <sub>2</sub> /250 ml
THM <sub>2</sub>	- - -	7.0 ml, 2 N Na <sub>2</sub> SO <sub>3</sub>	None
TOC <sub>2</sub>	- - -	7.0 ml, 2 N Na <sub>2</sub> SO <sub>3</sub>	0.25 ml H <sub>2</sub> SO <sub>4</sub> (conc)/125 ml
TOX <sub>2</sub>	- - -	7.0 ml, 2 N Na <sub>2</sub> SO <sub>3</sub>	0.50 ml H <sub>2</sub> SO <sub>4</sub> (conc)/250 ml

1. Final volume in composite sample bottles and cylinders fluctuated between 1,000 and 2,000 ml. Preservatives were added to bottles and cylinders prior to composite sampling.

2. THM, TOC and TOX samples were aliquoted from the same composite cylinder.



## SECTION 6

### QUALITY CONTROL

A quality assurance/quality control (QA/QC) program was developed encompassing analytical performance, sample handling, field quality control, travel blanks and laboratory certifications. The program was based upon procedures designated by the EPA in the Handbook for Analytical Quality Control in Water and Wastewater Laboratories as well as from experience gained during the project. The off-site laboratory QC Manual and the on-site Microbiology QC Manual are presented in Appendix A, Section 3.

#### DEVELOPMENT OF QA/QC PROGRAM

Quality assurance, the maintenance of sample integrity during sampling, shipping, log-in, chain of custody and report generation, is of equal importance in conjunction with analytical quality control because even perfect analytical performance cannot make up for any contamination or inappropriate handling of the sample prior to analysis. Some of the on-site QA procedures were developed at different times during the project and, therefore, were not performed on a continuous basis. Generally, these QA procedures were instituted in order to answer specific questions with respect to on-site sampling procedures and sample integrity during shipment to Pasadena.

#### QUALITY ASSURANCE

##### EEWTP FIELD QA

The major components of the on-site QA program were sample line checks, chemical preservation checks, travel blanks and spiked field samples.

##### Sample Line Checks

Extensive lengths of stainless steel pipe, PVC pipe and teflon tubing connected the process stream to the automatic composite samplers. These lines were flushed regularly to remove entrapped solids which could accumulate on the walls of the tubing and in the elbows of the piping. If the lines were not flushed, especially at the influent and blend sites where suspended solids were the highest, it is possible that certain chemical parameters in the water could adsorb to the deposited solids, or a plug of the solids themselves could break through into the sampling containers. Either of these possibilities could create unrepresentative samples.

The integrity of the sample lines was evaluated by comparing TOC, TSS, metals and turbidity measurements from the routine ACS samples with manual composite samples collected as close to the process stream and ahead of the sample lines as possible. The sampling interval of once per hour and volume of

## Quality Control

60 ml per interval was the same for both manual and ACS composites. The results showed that a flushing routine of once daily adequately prevented the build-up of solids in the lines.

### Chemical Preservatives

Chlorine reducing agents (sodium thiosulfate and sodium sulfite) and acid/base solutions were added to composite sample collection containers to preserve certain parameters during sampling. Organics composite samples taken from post-chlorination sites were tested amperometrically to assure the absence of a chlorine residual. The samples were rejected for analysis if a residual was detected. Cyanide, radiation and metals composite samples were tested for the proper pH, and also rejected if pH criteria were not met.

### Travel Blanks

Anions, nutrients, metals, TOC and THM travel blanks were analyzed at the off-site laboratory. Appropriate shipping bottles were filled with on-site Milli-Q water and preservatives and then shipped off-site in coolers packed with RWQTP samples. In addition, special travel blanks for VOA and CLS analyses were analyzed. For these blanks, off-site analytical grade water was shipped to the EEWTP where the water was carefully poured into a no-headspace cylinder and then placed in the ACS during the routine collection of VOA or CLS composite samples. Each blank was aliquoted and shipped to the off-site laboratory along with the routine samples. Time-zero and stationary blanks analyzed off-site served as travel blank controls, aiding in the evaluation of the travel blank results. The time-zero blank was analytical grade water analyzed immediately to determine baseline organics in this water. A second sample was collected and stored in an off-site laboratory refrigerator acting as a stationary blank until the travel blank arrived from the EEWTP. Then travel blank, stationary blank and routine samples were analyzed together.

On occasion the CLS stationary blanks revealed several trace level compounds which were not found in the time-zero or travel blanks, indicating contamination during sample storage. As a result, the storage time for CLS samples was minimized as much as possible to eliminate storage contamination. This is particularly crucial for the CLS analysis which detects organics at nanogram per liter (parts per trillion) concentrations. Other organics analyses which measure constituents at the microgram or milligram per liter level were not affected.

### Spiked Field Samples

On several occasions RWQTP local MWA finished water samples were substituted with spiked samples. The sampler bottles or cylinders scheduled to be placed in the ACS were instead filled with the spiked water at the sampling site and then delivered to the on-site laboratory for routine aliquoting and shipment. Off-site laboratory staff were unaware of which samples had been spiked so that these samples were processed and analyzed in a blind fashion along with the scheduled set of routine monitoring samples. Results of spiked samples

## Quality Control

were entered in the database as quality assurance data, and not as results from the site where the substitution had been made.

The following parameters were employed as spikes at least once during the project: metals, VOA, pesticides, herbicides, base/neutral extractables, acid extractables, nutrients, anions and cyanide.

### OFF-SITE LABORATORY

The off-site QA program stressed sample processing procedures from initial acceptance through log-in, storage and final report preparation. The key QA steps are shown in Figure 4.6-1.

## ANALYTICAL QUALITY CONTROL

### GENERAL APPROACH

The QC program for laboratory work is based on the EPA guidelines. There are three central aspects to the QC program.

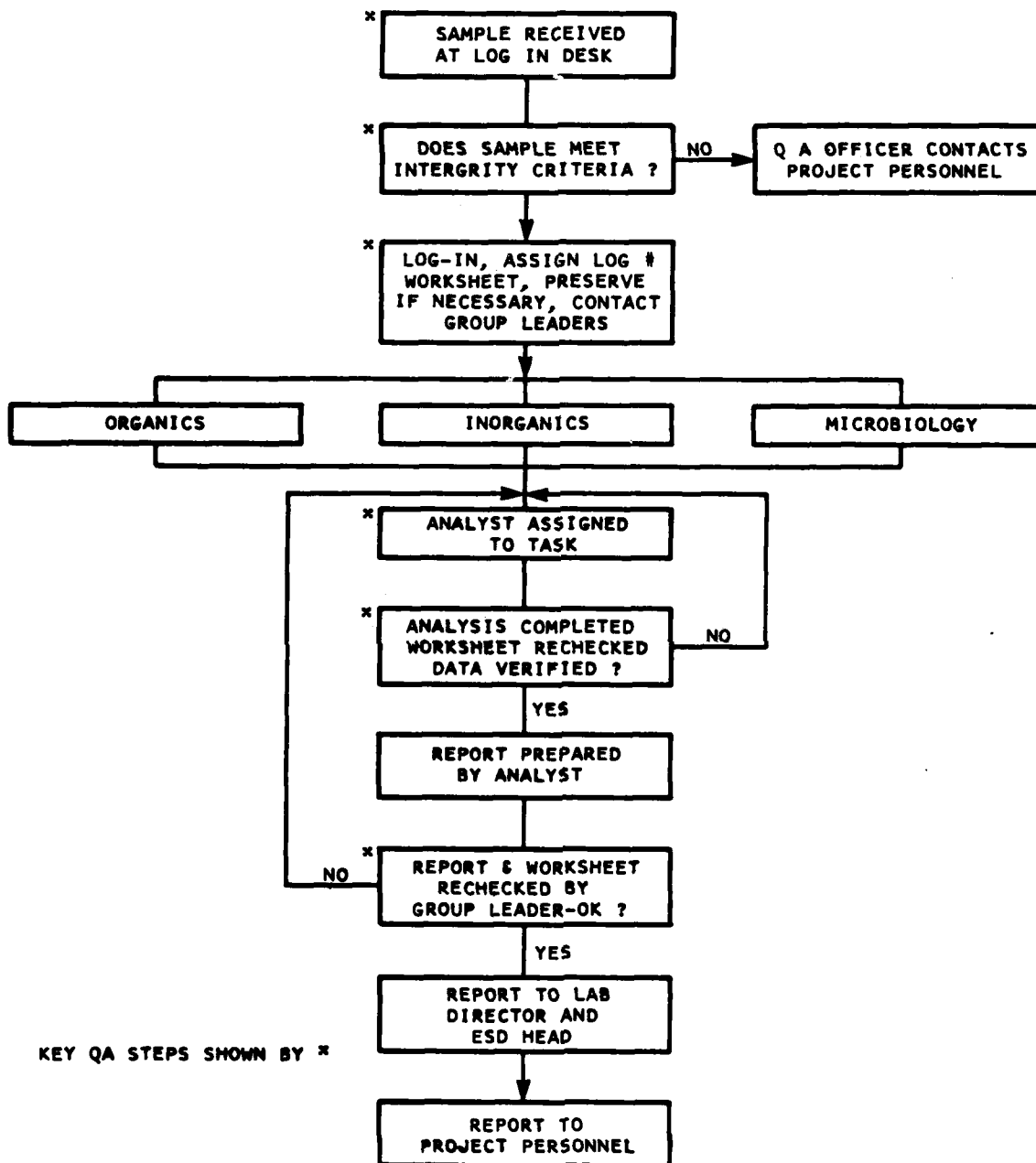
1. Checks on instrument performance were made on a routine basis.
2. Replicates, spikes and external standard reference materials to assure acceptable data were used in ten percent of the sample load. QC parameters were calculated from the replicates.
3. Verification tests on all sample sets ensured that final data were screened for consistency and accuracy by a responsible analyst.

### Instrument Performance

All instruments had a routine maintenance program which was followed on a regular basis to insure optimum performance. This maintenance involved checking electronic response, detection limits, and behavior on standard solutions. It also entailed glassware cleaning in the instrument where appropriate on a regularly scheduled basis. For example, the ICP glassware (nebulizer and torch) was cleaned after every eight to ten hours of use and performance checked for manganese to determine that the appropriate sensitivity and precision was being achieved.

All of the instrumental analyses performed for the project were subject to these same types of checks as summarized below:

ICP -	clean glassware, check performance on Mn, check for adequate performance on standards
CFA -	clean glassware; check absorbance of reagents, standards, behavior of autosampler
UV/VIS -	check performance on standards, check autosampler
IC -	check resolution of standard solution, check peak heights on standard solution.
AAS -	check behavior of autosampler, absorbance of standard solutions
TOC -	check recovery of standards, behavior of autosampler



**SAMPLE PROCESSING AT JMM-ERL**  
**FIGURE 4. 6-1**

## Quality Control

- TOX - check recovery of standards, combustion and detector efficiency
- GC/MS - check resolution on standard solutions, electronics
- TEM - check instrument resolution, diffraction patterns, and EDX performance

Results of these checks (and deviations) were entered into instrument log books or worksheets.

### QC During Analysis

Once instrument performance was verified through these routine checks the next stage of the analytical QC began. At the beginning of each analytical run a series of standards were analyzed to establish a standard curve which was compared to previous runs to verify operating conditions and monitor standard stability.

During an analytical run, duplicates were generally analyzed with a frequency of every tenth sample. The comparison between duplicates was used as a further guide to QC data. Based on an initial series of duplicates, quality control limits were established using Shewart control charts. When duplicate results fell outside the control limits, all data from that run were examined to locate the problem. Once the problem was located, the samples were re-analyzed. The control charts also permitted determination of long-term trends which could suggest a more subtle analytical bias. Control limits were recalculated after twenty to thirty duplicates.

In addition to duplicates, blanks and standards were analyzed at least every tenth sample to check for drift or contamination which could affect the quality of the results.

### Verification

Several additional QC measures were applied to insure optimum results. For example, whenever a sample was analyzed for enough parameters to perform a cation-anion balance (Ca, Mg, Na, K, Cl, SO<sub>4</sub>, NO<sub>3</sub>, F, alkalinity), the balance was checked to insure that it fell within a range of two to five percent, depending on the sample source. Should the balance exceed these limits, a series of remedial measures were undertaken. The first of these was to re-check the original data sheets to be sure that the poor balance was not due to simple clerical errors. Should that not account for the problem, the conductivity and analyses on other samples from the same site were used to identify the most likely erroneous test result. The original test run was re-checked and the sample re-analyzed for that parameter. If this did not solve the problem the whole sample was re-analyzed and individual tests checked by different analytical methods where possible.

The following table summarizes various tests for which alternative procedures were available and used as analytical performance checks.

## Quality Control

TABLE 4.6-1  
ALTERNATIVE CHECKING PROCEDURES

<u>Parameter</u>	<u>Cross Checking Method</u>
Cl, F, SO <sub>4</sub> , NO <sub>3</sub>	CFA and IC
Alkalinity	CFA and manual titration
Ca, Mg	AAS and manual titration
Pesticides	GC and GC/MS
THMs	GC and GC/MS

Samples were not verified for entry into the database until a senior staff member had examined the data to ensure that results were consistent with QC parameters and expected values. Aberrant data were re-checked to be sure they were not analytical artifacts.

### INORGANICS

#### Anions and Nutrients

For analyses conducted on the CFA, duplicates were analyzed a minimum of ten percent of the time and results compared to calculated control chart limits as discussed above. This included analyses for alkalinity, chloride, sulfate, fluoride, cyanide, TKN, ammonia, nitrate, and orthophosphate. In addition spikes were analyzed along with each analytical run to verify recoveries.

For other colorimetric, titrimetric, physical or instrumental analyses, a similar program of duplicates was used. For certain physical analyses (e.g., odor), it was not possible to utilize spikes so only duplicate analyses were performed. For other analyses (e.g., silica, MBAS) once greater than 90 percent recovery of spikes was demonstrated, the standards accompanying each run were used to monitor accuracy and duplicates were analyzed with each set of samples.

#### Major Cations and Trace Metals

For major cations and trace metals analyses three types of QC were used. First, QC standards consisting of known standard solutions at levels approximating those found in samples, were carried through the entire preparation procedure and analyzed along with each analytical run. Results of these standards were compared to known results for the standard. Second, duplicate aliquots of samples were carried through preparation and analysis ten percent of the time and the variance between duplicates plotted on control charts. Third, samples were spiked at levels near those expected in samples with a minimum frequency of ten percent and results compared to control charts. If any of these QC results were outside acceptable limits corrective action was taken. In addition, each analytical run was examined to be sure that CVs on individual analyses were reasonable and that there had not been excessive drift during the run.

## Quality Control

### Asbestos

A negative control blank using fiber free water was filtered and processed each day that samples were filtered. Two hundred milliliters of asbestos-free water must have no more than two fibers in twenty grid squares of a 200 mesh grid. If this limit was exceeded, the sample preparation area was thoroughly cleaned and procedures for the cleaning of glassware were monitored. No samples were refiltered until the negative blanks were within acceptable limits.

### Radiation

For radiation, daily QC consisted of analysis of duplicates with each set and comparison of the results of the duplicates to calculations of the expected counting error. In addition, EPA check samples were analyzed four times a year and results verified to be within the expected error.

## TRACE ORGANICS

### Total Organic Carbon Analysis

All samples analyzed by TOC were run in duplicate. The range of values of the duplicates at two sites, Blue Plains nitrified effluent and EEWTP finished water, were plotted for precision control charts. Spikes were performed on one duplicate sample from every other set of samples, usually eleven samples per set. The percent recovery of this spike, usually 4 mg/L, was plotted on an accuracy control chart. Blanks were run daily at the beginning and in the middle of the analysis to assure that no contamination was being introduced into the machine. Standards at 1, 2, 3, 5 and 10 mg/L were run at the beginning and end of each set of samples.

### Total Organic Halide Analysis

All samples analyzed by TOX were run in duplicate. The range of values of the duplicates at two sites, Blue Plains nitrified effluent and EEWTP finished water, were plotted for precision control charts. Spikes were performed on at least one duplicate sample for every twenty samples. The percent recovery of this spike, usually 100 µg/L, was plotted on an accuracy control chart. Three blanks were run at the beginning of each day and one blank was run every ten samples. Three dichlorophenol standards were run at the beginning of the day. These standards were equivalent to 100 µg/L Cl<sup>-</sup>.

### Trihalomethane Analysis

Several blanks, purified water, and internal standard blanks were analyzed along with each set of samples. Standards at 5, 10, 25, and 50 µg/L were run daily in triplicate and additional standards were run to monitor instrument drift.

## Quality Control

### Herbicide/Pesticide/PCB Analysis

Because most of the herbicide/pesticide/PCB samples did not contain any of these parameters, duplicates were not usually run. However, with each set of samples a recovery of the compounds from water was performed. The herbicides were spiked into the water at 1 µg/L and the pesticides at 0.1 µg/L. The pesticide extract was also used for the PCB analysis; therefore the recovery of the pesticides provided quality assurance for the PCBs. Extracts of blank water were also analyzed with each set.

### Closed-Loop Stripping Analysis

One duplicate sample was run for each set of CLS samples run, usually nine samples per set. The recovery of a 100 ng/L standard was also examined for each set. In addition, the area counts of the internal standards were examined. A sample was spiked at 50 ng/L every other set. All of the recovery, duplicate and spike data were tabulated. A system and water blank were analyzed with each set of samples run.

### Volatile Organic Analysis

The internal standard area count was tabulated and the standard deviation of these area counts was determined with each set of samples. Duplicates or spikes at 2 µg/L were run on every tenth sample. Water blanks were run at the beginning of each day, and a 10 µg/L standard was run at the end of each day.

### Base-Neutral Analysis

The internal standard area count was recorded and the standard deviation determined on each day this analysis was done. Duplicates or spikes at 10 µg/L were run every tenth sample. A water blank was extracted and analyzed with each set of samples. A 12.5 µg/L equivalent standard was run at the end of each day.

### Acids

Duplicate samples were analyzed every tenth sample. In addition, a spike at 10 µg/L was run every tenth sample. A water blank extract and a 20 µg/L equivalent standard was run every day.

## MICROBIOLOGY

### Endotoxin

The sensitivity of the Limulus amoebocyte lysate was determined with known amounts of E. coli endotoxin diluted in pyrogen-free water whenever an assay was run. The sensitivity of the lysate should be in the range of 0.006 - 0.05 ng/ml. A negative control consisting of pyrogen-free water was also tested whenever an endotoxin assay was run. The negative control should result in no gelation of lysate. The assay was repeated whenever the sensitivity of the



## Quality Control

lysate was out of the range of 0.006 - 0.05 ng/ml or whenever there was gelation in the negative control.

### Parasites

Quality control in parasitology is less well-defined than in other areas of microbiology. Maintenance of sample integrity during processing was accomplished by preserving the filters with formalin and refrigeration after sampling until the filters were processed.

### Salmonella, Coliforms and Standard Plate Count

The on-site and off-site microbiological laboratories maintained a quality assurance program which included the following procedures.

1. A written record of all media prepared was maintained in a log book, including date prepared and pH of media.
2. Operating temperatures of incubators were logged in daily and adjustments were made when necessary. Autoclave records (pressure, temperature and run-time) were maintained.
3. Quality of laboratory pure water was checked annually for bacteriological suitability according to Standard Methods.
4. Positive and negative controls were used each time an analysis was performed.

### Virus

During all phases of enteric virus monitoring, the samples were protected from contamination. When several samples were to be reconcentrated on the same day, the cleanest sites, such as finished waters, were reconcentrated first, followed by progressively dirtier water. Equipment such as pH probes were decontaminated with a strong hypochlorous acid solution, 100 mg/L  $\text{Cl}_2$ , then rinsed with sterile deionized water and sodium thiosulfate between samples.

Reconcentration of the samples took place in a room separate from the cell culture preparation area to prevent contamination of the cell lines.

## TOXICOLOGICAL

### Ames Mutagenicity

The quality assurance program for the Ames mutagenicity assay consisted of the following steps:

## Quality Control

1. The tester strain genotype for each assay culture was verified.
  - a. The histidine requirement was verified by streaking the culture on minimal agar plates both with and without histidine.
  - b. The deep rough (rfa) character was tested for crystal violet sensitivity.
  - c. Ampicillin resistance (R factor) was checked by growing cultures in the presence of ampicillin.
2. The genotype of four revertant colonies per assay was verified by streaking revertants on histidine-free minimal agar plates. Only true revertants can grow in the absence of histidine.
3. Positive controls of the known carcinogens 2-aminofluorene and methylmethanesulfonate were included in each assay.
4. Because of initial high spontaneous reversion frequencies, the tester strains were re-isolated during the last several weeks of August 1981. Beginning with assays performed after 1 September 1981 an acceptable range of spontaneous revertants on control plates without added mutagen was instituted; 9 - 26 for TA98, 11 - 30 for TA 98 + S9, 73 -180 for TA 100 and 85 - 154 for TA100 + S9. These values were calculated from +/- two standard deviations of the mean spontaneous reversion for each strain. The sample population consisted of all spontaneous revertant plates used in the assays conducted between 1 September 1981 and 9 March 1982.

### Mammalian Transformation Assay

The plating efficiency and growth rate of the cells were routinely monitored. If changes in the plating efficiency or growth rate of the cells were noted, steps were taken to determine the source of the problem. No assays were carried out until the problem was eliminated.

A known carcinogen, 3-methylcholanthrene and a negative solvent blank (DMSO) was included whenever samples were being analyzed.

## LABORATORY CERTIFICATION

### OFF-SITE LABORATORIES

The off-site laboratory (JMM-ERL) is certified by the State of California to conduct water analyses for contaminants regulated by the National Interim Primary Drinking Water Regulations (NIPDWR) and the State of California. JMM also has certification with 25 other states based on reciprocity, demonstration of acceptable performance on check samples and a description of laboratory facilities.

## Quality Control

### EEWTP (ON-SITE)

The EEWTP laboratory was certified by the EPA Region III for NIPDWR contaminants analyzed on-site. The laboratory was certified for total coliform analyses and given interim approval for THM analyses. The on-site EPA inspection required for final THM certification could not be scheduled prior to the completion of EEWTP operation. On-site THM analyses were conducted for engineering studies whereas routine composite monitoring of THMs was conducted at the off-site laboratory. The on-site laboratory successfully passed EPA WS 011 THM performance evaluation samples.

### EAL CORPORATION (TRITIUM ANALYSIS)

Tritium was analyzed by EAL Corporation, a California and EPA certified radiation laboratory.

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## **CHAPTER 5**

### **DATA ANALYSIS TECHNIQUES**

The extensive sampling programs conducted during the EEWTP project have resulted in numerous measurements of a large number of parameters at a variety of sites. In order to summarize and interpret these results, it is necessary to organize, present, reduce, and evaluate the observed data.

The first section of this chapter describes the statistical techniques which have been used for data reduction and interpretation. Section 2 deals with the methods used in this report to organize, tabulate, graph and otherwise summarize the data which was obtained during the two years of extensive monitoring. Section 3 describes the methods and statistical techniques used to evaluate the EEWTP process performance and effluent water quality.

## SECTION 1

### STATISTICAL CHARACTERIZATION OF DATA

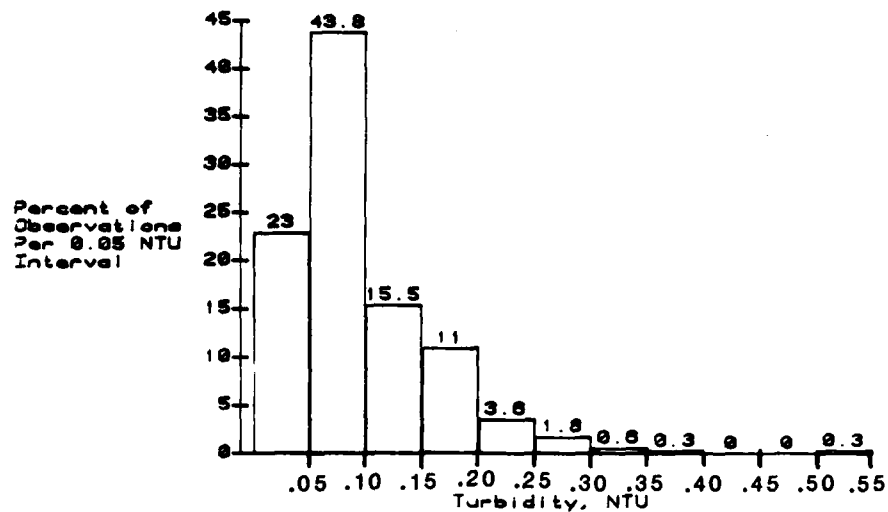
The characteristics of the influent waters and the performance of the experimental plant vary considerably over time, as do the characteristics of finished waters both at the EEWTP and the monitored off-site water treatment plants. The statistical characterization of the large quantities of data taken at each of these sites required the selection and application of appropriate statistical methods. This was an important step in the overall study and involved the application of statistical techniques to determine not only the central tendencies, or "mean" values of the observed data, but also to assess the degree of the variance about that mean value. An important aspect of this data characterization is to accurately describe the frequency distribution of water quality parameters at the different sampling sites.

#### SELECTION OF A DISTRIBUTION MODEL

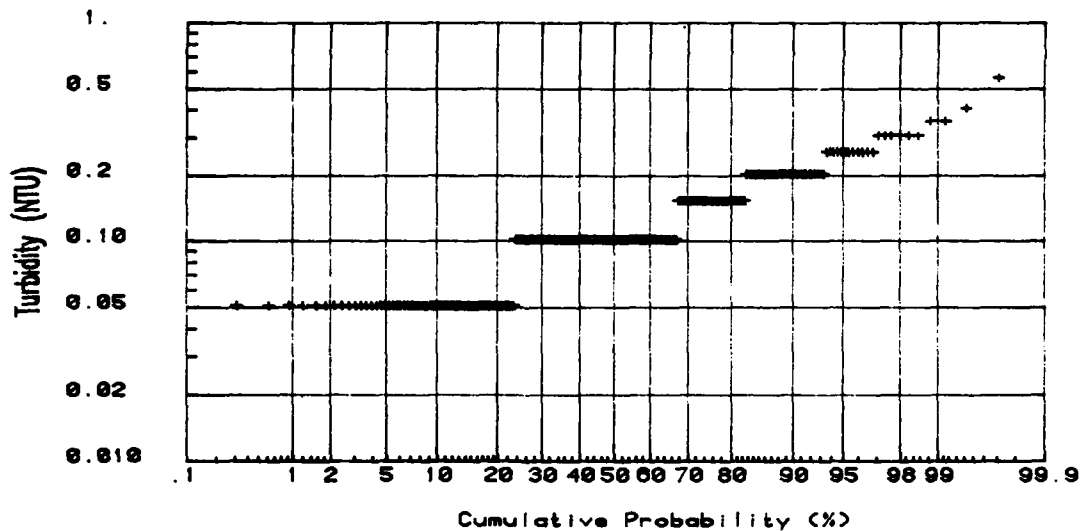
The sample "frequency distribution" of a data set describes the relative proportion of sample observations for each value, or range of values, encountered for the subject parameter. A sample set drawn from the population of a variable will exhibit a sample frequency distribution which tends to approach the population distribution as the sample size increases. Figure 5.1-1(a) describes the sample frequency distribution of turbidity values observed in EEWTP finished water during the first year of plant operations. Figure 5.1-1(b) shows the cumulative frequency distribution for this same data set. For each value of turbidity shown on the ordinate of Figure 5.1-1(b), the percent of samples with concentrations below that value is represented by the X-coordinate (abscissa value) of the plotted curve. Plots of this type are quite useful in evaluating plant reliability.

There are a large number of probabilistic models which have been applied to characterize the underlying populations from sample frequency distributions such as that shown in Figure 5.1-1. The more common of these probability distributions are based on underlying physical principles. These distributions have been given proper names and are tabulated for facility of use. The "normal" distribution model, for example, represents the distribution of the sum of a number of uniformly distributed random variables. As the number of variables in the sum approaches infinity, the distribution of the sum of random variables will approach the normal distribution (Benjamin and Cornell, 1970).

Even where no fundamental argument exists to suggest that a model is appropriate, it is convenient to adopt such a common distribution model simply because it lends itself to ready statistical interpretation. In this case, the important criterion is that the model accurately describe the observed data. A model may also be appropriate if one of its estimators has useful physical meaning with respect to interpretation of the data.



(a) Frequency Distribution of Turbidity Values in Phase IA Finished Water (Based on noon grab samples only)



(b) Cumulative Frequency Distribution of data shown in Figure 5.1-1, above

**FREQUENCY DISTRIBUTION OF TURBIDITY IN  
EEWTP FINISHED WATER  
( PHASE IA )  
FIGURE 5. 1-1**

Several probability models were considered for describing the probability distribution of water quality parameters at the different sampling locations for this project. Previous work by Dean (1976) and by McCarty, et al (1982) have indicated that concentrations of water quality parameters in wastewaters and treatment plant effluents generally follow log-normal distributions. These findings were tested for the EEWTP project by evaluating different model parameters for various sets of water quality monitoring data and then comparing the model predictions with actual frequency distributions of the observed results. Normal and log-normal distributions received the most attention due to the findings from previous studies and because these distributions lend themselves most readily to statistical interpretation.

Analysis indicated that although the log-normal distribution was often more adequate than the normal distribution in describing the probability distributions of monitored water quality parameters, there were also cases where the normal distribution showed equally good or better fits. The alternative distribution models, procedures used for their evaluation, and recommendations for this project are all described more fully in Appendix B. Probability plots of various data sets with corresponding plots of normal and log-normal line fits have been provided in Appendix B for comparison.

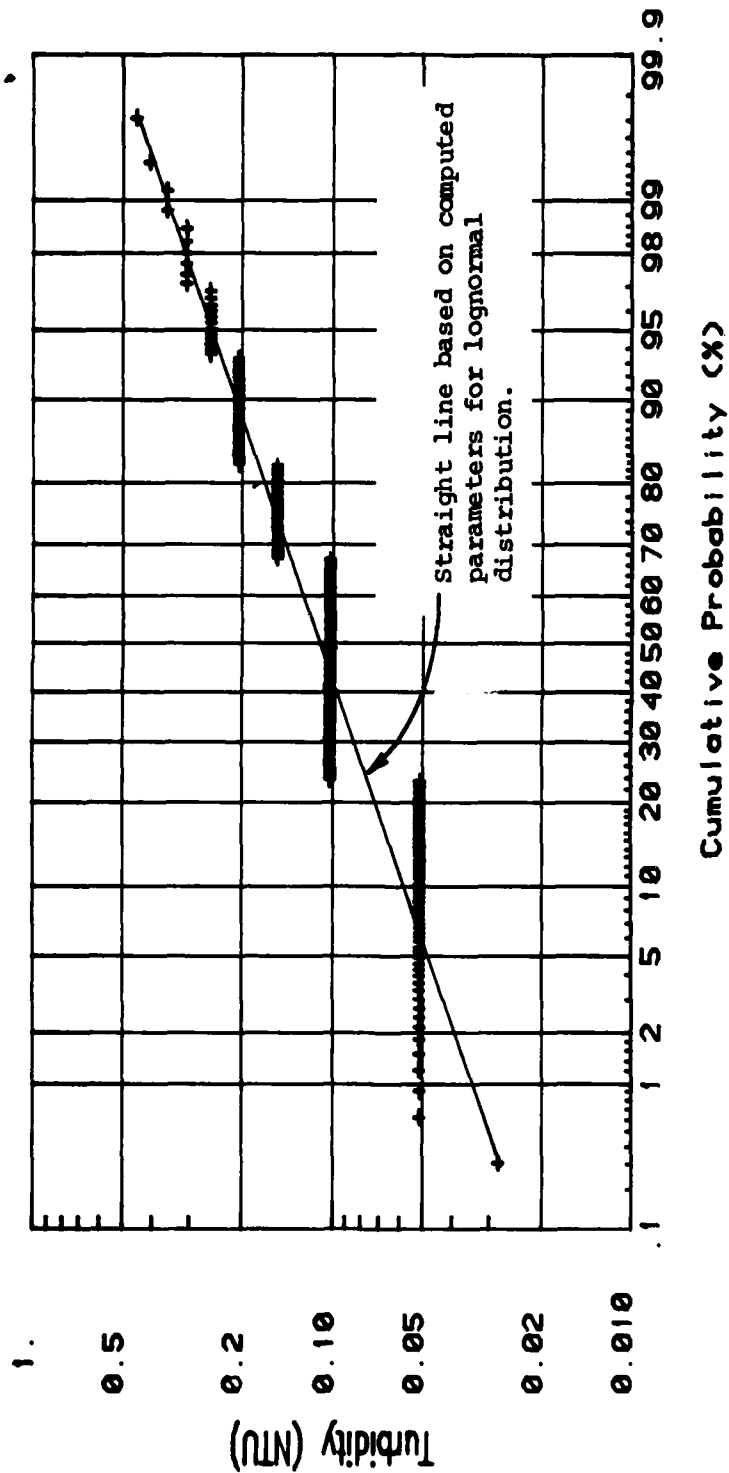
Application of the log-normal distribution to the TOC data previously discussed is shown in Figure 5.1-2. In this figure, the straight line represents the modeled probability distribution using distribution parameters (geometric mean and variance) calculated from the actual data. As is evident from Figure 5.1-2, the log-normal distribution model closely approximates the observed frequency distribution for turbidity in the EEWTP finished water.

For the purpose of statistically summarizing the project data, parameters for both the normal and log-normal distribution models have been calculated. The log-normal probability distribution was selected because it often provides the most reasonable description of the population distribution, based on observed data. This makes the log-normal distribution useful for evaluating plant performance and reliability.

The normal distribution was selected for two reasons. First, it represents a probability distribution with which most readers will be able to easily identify, since the central tendency of this distribution is represented by what is commonly known as an arithmetic "average". Second, and of more importance, is the application of the arithmetic mean as a measure of cumulative intake for certain water quality parameters causing potential chronic health effects. The arithmetic mean of individual sample concentrations represents the final concentration which would be achieved if all of the individual samples were composited. For parameters causing potential chronic health effects, this is a useful concept.

The distribution models used for this project, as well as the algorithms used to calculate their parameters, are discussed more fully in the following section.





CUMULATIVE FREQUENCY OF TURBIDITY IN  
EEWTP FINISHED WATER  
FIGURE 5. 1-2

## Statistical Characterization of Data

### CHARACTERIZATION OF DATA

In order to present the analytical results from the extensive sampling conducted during this project, it is necessary to summarize the results by characterizing sample data in statistical terms. Interpretation and evaluation of the results, as presented in this report, will rely on those statistical parameters which are most meaningful for the water quality parameters under consideration. In anticipation of needs for this information, monitoring data for each water quality parameter at each site and for each relevant time period were statistically characterized, using the two distribution models previously discussed, as well as frequency percentile based on the raw data. This statistical information has been determined for all sites and parameters of interest and is reported in the tables of Appendices F, G, and H. Typical table cells from those appendices are shown in Table 5.1-1. The definition and significance of the various statistical parameters are discussed below.

TABLE 5.1-1  
TYPICAL TABLE CELLS<sup>1</sup> WITH STATISTICAL  
SUMMARIES (APPENDICES F, G, AND H)

	<u>Blue Plains Nitrified Effluent</u>	<u>Potomac River Estuary</u>	<u>EEWTP Blend Tank</u>
Chloroform: LLE ECD (IDL = 0.1 µg/L; MDL = 0.3 µg/L)			
No. of Samples	171	187	253
No. Detected	166	163	250
No. Above MDL	166	149	250
Arithmetic Mean	2.73	0.83	1.89
Standard Deviation	1.33	0.53	1.13
Geometric Mean	2.45	0.67	1.68
Spread Factor	1.70	2.12	1.60
Median Value	2.6	0.8	1.7
90% Less Than	3.8	1.6	2.6

1. From Table F-10, Appendix F.

#### SAMPLE SIZE

The first group of items in the statistical cells of Table 5.1-1 provide information about the sample population which was available for calculating the remaining statistics.

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OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
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ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

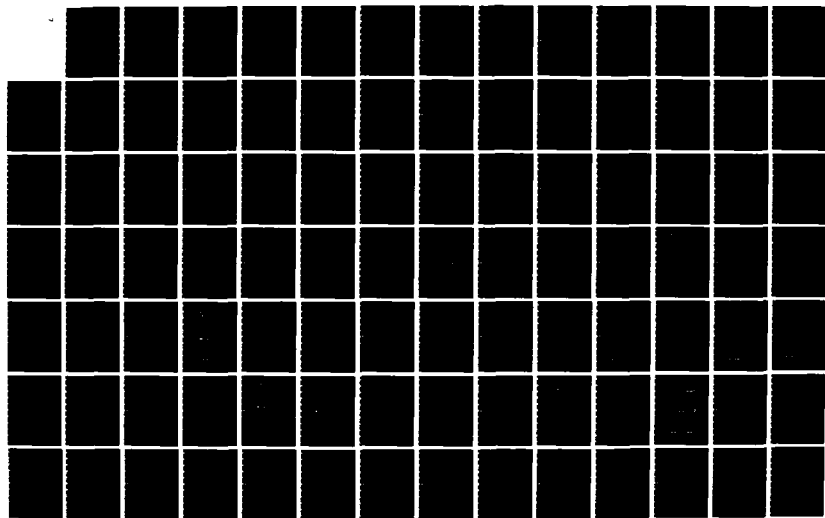
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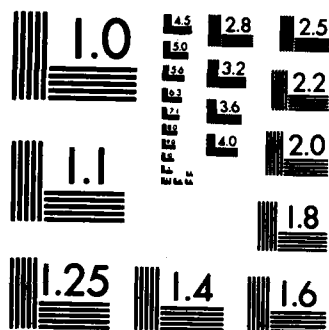
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F/G 13/2

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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

## Statistical Characterization of Data

### Number of Samples

This is the total number of observations (water quality measurements or sample analyses) made for the given parameter for the given site and during the time period of interest.

### Number Above MDL

This figure represents the number of results with values above the method detection limit for the parameter of concern. The method detection limit (MDL) of the analytical method is indicated in parentheses under the parameter name. The "Number Above MDL" can be interpreted as the number of quantified samples. For inorganic and microbiological parameters this represents the number of "positive" results. For synthetic organic chemicals (SOCs), the MDL is the level above which reasonably reliable quantification is possible, and the "Number Above MDL" represents the number of quantifiable samples which were not reported as either "ND" (not detected) or "NQ" (not quantifiable).

### Number Detected by Instrument

This number applies only to SOCs. For these compounds, analysis may lead to findings of "not quantifiable" (NQ) which means that the compound was detected by the instrument, and its mass spectra was identified, but the peak height was so small that reliable quantification was not possible. With a reported finding of NQ, confidence that the compound was actually present in the water sample (rather than as artifact of the analytical method) is relatively low (below 90%). For the SOCs, the "Number of Samples" minus the "Number Detected by Instrument" represents the number of samples which were reported as "ND". Similarly, the "Number Detected by Instrument" minus the "Number Above MDL" represents the number of samples which were reported as "NQ".

## PROBABILITY DISTRIBUTIONS - MODEL PARAMETERS

As previously discussed, parameters for two different distribution models have been determined for the vast majority of data collected during this project. The statistical table cells indicate model parameters for both the normal and log-normal probability distributions. The parameters calculated for each distribution are the "mean" and "variance".

### Arithmetic Mean

The arithmetic mean,  $\bar{x}$ , defines the central tendency of samples drawn from a normally distributed sample population. This sample arithmetic mean is the "best" estimator for the true population mean. For a given set of data, the arithmetic mean is calculated simply as the "average" of all the data values; that is, as the sum of all values divided by the total number of observations.

### Standard Deviation of the Arithmetic Mean

The standard deviation (s.d.) is a statistic used to quantify the scatter of the data. The formula used for its calculation is described in Appendix B. For a random variable which is normally distributed, 68.3 percent of the values will lie between concentrations represented by the mean minus the standard deviation ( $\bar{x} - \text{s.d.}$ ) and the mean plus the standard deviation ( $\bar{x} + \text{s.d.}$ ); and 95 percent of the values will lie between  $\bar{x} - 2\text{s.d.}$  and  $\bar{x} + 2\text{s.d.}$

For parameters where health effects might be related to cumulative ingestion over time, the arithmetic mean provides a good measure of the likely total exposure. For example, if a consumer drank ten one liter portions of water, his total intake of a given contaminant would be precisely equal to the arithmetic average of that contaminant's concentration (mg/L) in each of the one liter portions, multiplied by ten liters. This kind of information on cumulative intake is important with respect to parameters with cumulative health effects, and the arithmetic mean represents a useful tool for its characterization. For some parameters, cumulative intake is less important than acute effects due to a single dose. In these cases, statistical parameters which define the probability of any given single dose are more applicable.

### Geometric Mean and Spread Factor

Because many of the parameters measured during this project were generally best described by log-normal probability distributions, the geometric mean and spread factors were important statistics for describing the frequency distribution of water quality parameters at sites of interest. This information can be used to evaluate treatment performance as well as plant reliability, as discussed in Section 3 of this chapter.

#### Geometric Mean

The geometric mean,  $M$ , describes the central tendency of a log-normally distributed samples. This sample geometric mean is the "best" estimator of the population geometric mean. For a given set of water quality data, the geometric mean is calculated by taking the log of each concentration, calculating the average value of those values and then taking the antilog of the mean so obtained. This is equivalent to calculating the  $n$ th root of the product of all the data values, where  $n$  is the number of observations or data points. The calculation is shown in greater detail in Appendix B.

#### Spread Factor

The spread factor,  $S$ , is a measure of the scatter of the observed data. The spread factor is calculated by taking the log of each value, calculating the standard deviation of the log values, then taking the antilog of the standard deviation so obtained. For a population which is log-normally distributed, 68.3 percent of the values will lie between concentrations represented by  $M/S$  and  $MS$ , and 95.5 percent of the values will lie between  $M/S^2$  and  $MS^2$ .

### FREQUENCY DISTRIBUTION PERCENTILES

The final statistical parameters shown in the cells of Table 5.1-1 are the "median" and "90 percent less than" values. These parameters are determined directly from the frequency distribution of the raw data, as discussed below.

#### Median Value

The median value, or "50 percentile", is the value which is exceeded by fifty percent of the samples in the data set. In other words, half of the samples have concentrations greater than this value, while the other half have concentrations less than or equal to this value. The median is determined by ranking all of the samples and selecting the sample for which fifty percent of the data have values less than or equal to that selected.

#### 90 Percentile

The 90 percentile value is that value which is exceeded by only ten percent of the samples in the data set. As with the median value, it is determined by ranking all of the samples in the set. The 90 percentile is selected such that at least ninety percent of the data are less than or equal to that value. Because of round up, it is conceivable that over ninety percent of the data fall below that value. For example, if there are fewer than ten samples in the data set, the "90 percent less than" level will be calculated as the maximum value.

These percentiles are useful statistics for the table cells primarily because they provide immediate information about process reliability based upon actual observed values. It should be recognized that, if a population is perfectly log-normally distributed, the population median will be precisely equal to the geometric mean. Similarly, the "90 percentile" for the true population can, for log-normal distributions, be calculated directly from the geometric mean and spread factor, which define the line of the modeled lognormal distribution; see Figure 5.1-2. A comparison of these values with the observed median and 90 percentile values would provide a check as to how well the modeled population distribution agrees with the observed sample distribution.

### DATA ANALYSIS FOR POPULATIONS CONTAINING UNQUANTIFIED DATA

Water quality data frequently contain results which lie below the analytical detection limit. Such data are simply reported as "not detected" (ND) or detected but "not quantifiable" (NQ) and actual concentrations are, in a sense, masked from view. This prevents a complete description of the frequency distribution in lower ranges of values and presents a significant problem in determining the parameters for probability distributions. Methods of addressing this problem are discussed below for each of the distribution models utilized in this project. Another type of problem arises for certain synthetic organic chemicals which are tentatively identified in water samples. These SOC's are tentatively identified by their mass spectra, but because no analytical standard was available for comparison during analysis, there is little confidence in

quantifications. Data analysis of these results is discussed in a following subsection entitled "Reporting Compounds Detected But Not Quantified".

## PROBABILITY DISTRIBUTIONS WITH UNQUANTIFIED DATA

### Alternative Methods

There are several available approaches for analyzing data of which some is below the detection limit. These include the following:

1. Direct computation using simplifying assumptions
2. Linear regression of the distribution plot using available quantified data
3. Statistical estimation techniques (maximum likelihood techniques, sometimes referred to as expectation-maximization, or E-M techniques)

These techniques are more fully described in Appendix B and are briefly discussed below.

Direct Computation Using Simplifying Assumptions. This technique involves application of the common statistical calculations for determining distribution parameters with arbitrary assumptions used to convert "not detected" samples to numerical values. One approach, for example, would be to set NDs to zero. A more conservative approach, would be to set all NDs to a value equal to the detection limit. There are clear disadvantages to each approach. Compromise solutions are available at all values between these two extremes with a value of one half the detection limit being perhaps the most rational.

Linear Regression of the Distribution Plot. McCarty, et al (1982), have demonstrated that data may be analyzed by log-normal statistics by fitting a straight line to the log-normal probability plot of the data using a linear least-squares regression. This technique involves ranking the data using all samples (including the NDs) but only plotting the points which were actually quantified. In this case, the distribution curve below the detection limit is obtained by extrapolating the fitted line into that region. Similar techniques may be applied to normally distributed data. If the data is less well fitted by the normal distributed, however, the parameter estimates will be less certain.

Statistical Estimation. Techniques have been published (Hald, 1949; Gupta, 1952; Wood, 1982) which address the issue of populations with masked or censored data. Rigorous applications of these techniques has led to the formation of an algorithm for estimating the distribution parameters with "maximum likelihood". The underlying basis of this approach is to choose estimates of population geometric mean and spread factor which have the highest likelihood of producing the observed sample data.

The algorithm, provides the most statistically rigorous determination of distribution model parameters of the approaches examined. The algorithm utilizes an iterative technique to estimate model parameters, and is more fully described in Appendix B. It is equally suitable for normal or log-normal distributions. For the latter case, the normal distribution algorithm is simply



## Statistical Characterization of Data

applied to the logarithms of the data values. While offering the most statistically rigorous approach, this technique has somewhat greater computational requirements than the other two methods.

### Selected Approach

The approach utilized in statistically characterizing the data for the EEWTP project is discussed in this section. In modeling probability distributions for data from this project, data below detection limits were handled as shown in Table 5.1-2. Conventional statistics are utilized for the arithmetic mean and standard deviation, using simplifying assumptions for unquantified data as shown in Table 5.1-2. Such assumptions offer computational ease and are readily understood. These assumptions represent a compromise position, relative to the extreme values (zero or equal to the detection limit).

Because the log-normal distribution generally fit the data more closely, a more rigorous statistical procedure was utilized to estimate the geometric mean. The algorithm was only applied, however, when at least fifteen percent of the data were quantified. The fifteen percent cut-off criteria for use of the technique was based on concerns that the algorithm may require undue convergence time for cases with fewer positive samples. The algorithm was selected over the linear regression technique because the latter is not statistically rigorous. The Thomas plotting positions used for the plot are arbitrary and the linear regression has no special properties for producing best estimates of model parameters.

### REPORTING COMPOUNDS DETECTED BUT NOT QUANTIFIED

As discussed in Chapter 4 confirmed quantitative analysis of specific organic compounds by GC/MS requires that standards be run for the compounds of interest. If possible, the analysis of replicate field spikes should be conducted for the development of precision and accuracy data. In addition to the compounds which were being monitored in this manner, numerous additional organic compounds may be present in any given sample. If such a compound is amenable to the isolation and separation techniques of a given method, it will be detected by the mass spectrometer and its mass spectra will be available. For many compounds, identification is possible by comparing the spectra with a computerized library of known spectra, as discussed in Chapter 4. For those compounds, where standards have not been run, confident quantification of the compound's concentration is not possible. Moreover, the identification of the compound may only be considered as "tentative", as it has not been "confirmed" through the running of a standard (Christman, 1982). In order to provide some feel for the relative amount of the compound present, however, it is possible to calculate tentative concentrations based on peak areas of similarly structured compounds for which there are standards. Such estimated concentrations are tentative and are calculated only to provide relative information about the size of the detection peaks which emerged from the gas chromatograph.

# Statistical Characterization of Data

TABLE 5.1-2  
PROJECT APPROACH FOR ESTIMATING STATISTICAL PARAMETERS  
WITH DATA BELOW DETECTION LIMITS

<u>Situation</u>	<u>Arithmetic Mean and Standard Deviation</u>	<u>Geometric Mean and Standard Deviation</u>
All data either ND <sup>a</sup> or NQ <sup>b</sup>	Mean = NQ or ND Standard Deviation not reported	Geometric Mean not reported Spread Factor not reported
Some data above MDL <sup>c</sup> , but less than 15% of data quantified	Mean and standard deviation calculated and reported using standard algorithms and following conventions: ND = 1/2(IDL) <sup>d</sup> NQ <sup>e</sup> = IDL + 1/2(MDL-IDL)	Geometric Mean not reported  Spread Factor not reported
15% or more of data quantified	Mean and standard deviation calculated using standard algo- rithms and following conventions: ND = 1/2(IDL) NQ = IDL + 1/2(MDL-IDL)	Geometric Mean and Spread Factor calculated by maximum likelihood procedure

a. ND = Not Detected.

b. NQ = Not Quantifiable

c. MDL = Method Detection Limit.

d. IDL = Instrument Detection Limit; for inorganic and microbiological para-  
meters, IDL=MDL = detection limit.

e. Organic chemical compounds only.

## Statistical Characterization of Data

Analysis of compounds which fall into this category consists of recording the number of times a compound is detected at a given site and keeping track of the range of tentative concentrations determined by the above methods. This information is presented for each of the applicable SOC analyses and at each monitored site in Tables 17 to 20 of Appendices F, G, and H.

The techniques used to organize the information into tabular reports are discussed in the following section, as are the graphical methods which are used for more detailed presentation.

## **SECTION 2**

### **DATA PRESENTATION**

As discussed in the previous section, all data taken over the course of this project have been statistically characterized by site, parameter and time period of interest. This statistical information has been compiled in tabular reports which are presented in the Appendices. Evaluation of the EEWTP process performance and evaluation of the influent and effluent quality is discussed in Chapters 6 through 9 and draws heavily upon these statistical summaries. Important information for parameters of interest is extracted and summarized in those sections. In addition, graphical information is presented where appropriate to give additional background for evaluation and discussion. This section describes how the tabular reports are organized for the Appendices and discusses the methods applied for graphical presentation of data.

#### **TABULAR SUMMARIES**

Statistical data cells of the type shown in Table 5.1-1 have been organized into appendices to this report and represent a full documentation of the analytical results. The tabular reports are organized by parameter group and site, as described below.

#### **TABULAR GROUPS - APPENDICES**

Water quality monitoring results have been organized into six groups of tabular reports based on sites monitored. These are presented in Appendices F through H, as indicated below.

1. Characterization of Influent (Appendix F)
2. Process Performance, Phase IA (Appendix G-1)
3. Process Performance, Phase IB (Appendix G-2)
4. Process Performance, Phase IIA (Appendix G-3)
5. Process Performance, Phase IIB (Appendix G-4)
6. Characterization of Finished Waters (Appendix H)

These groups of tables are briefly described in the following subsections.

##### **Characterization of Influent**

Statistical data characterization of influent water quality at the EEWTP is presented in the 22 tables of Appendix F. The summary statistics in the appendix are based on all available monitoring data, covering a 23 month period for most parameters. Sampling occurred between 16 March 1981 and 14 February 1983 unless otherwise noted in Appendix F. The individual tables represent data from "groups" of parameters, as discussed in a later section of this chapter.

## Data Presentation

The influent tabular reports include the following three sampling sites: Blue Plains nitrified effluent, Potomac River estuary, and EEWTP blend tank. The sampling locations and frequencies are as described in Chapter 3. The two influent sources were sampled at the EEWTP, prior to blending. Blend tank sampling was from either the blend tank effluent or the blend tank mixing area, as discussed in Chapter 3.

### Process Performance

Appendix G presents the statistical characterization of monitoring data collected at the EEWTP process locations. Separate groups of tables are provided for each of the phases of operation in Appendices G-1 through G-4, reflecting process performance for each of the configurations tested at plant scale. The tables in each section represent "groups" of parameters, as previously described for the characterization of influents.

The "Process Performance" tabular reports present summarized data at each of the following six EEWTP sites.

1. Blend tank
2. Post sedimentation
3. Gravity filtration
4. Lead carbon column effluent
5. Final carbon column effluent
6. Finished water

Sampling locations and frequencies have been described in Chapter 3. Special cases and exceptions to the reported locations are noted separately in the tables of Appendix G. Descriptions of the data utilized for the different operating phases follow.

Phase IA. (Appendix G-1) This phase of operation extended from 16 March 1981 to 16 March 1982, inclusive. During this time period, the plant was operated with surface aeration, alum/polymer coagulation and sedimentation, intermediate oxidation, and disinfection with chlorine, gravity filtration, granular activated carbon adsorption (fifteen minute empty bed contact time) and final disinfection with chlorine. Operating conditions are described in detail in Chapter 7 of this report.

Phase IB. (Appendix G-2) This phase of operation extended from 17 March 1982 to 6 July 1982, inclusive. Process configuration was identical to Phase IA with the exception of intermediate oxidation/disinfection, which utilized ozone in lieu of chlorine as the oxidant. Because of potential implications of the ozone, on downstream processes and processed water quality, statistical information from this was reported separately from the first year of alum operation (Phase IA).

Phase IIA. (Appendix G-3) This phase of operation was evaluated between 16 July 1982 and 14 February 1983. The process configuration during this phase consisted of lime/ferric chloride coagulation and sedimentation, recarbonation,

gravity filtration, granular activated carbon adsorption (thirty minute empty bed contact time) and final disinfection with ozone followed by chloramination. Further descriptions and detailed operational conditions are discussed in Chapter 8.

Phase IIB. (Appendix G-4) This phase represents plant monitoring between 15 February 1983 and 16 March 1983. Plant configuration and operating conditions during this period were essentially the same as during Phase IIA. Data characterization for this period has been presented separately for two important reasons. Firstly, it was necessary to statistically characterize Phase IIA at an early date in order to evaluate the results in a timely enough manner to meet scheduling constraints for producing this report. This required that data included in the statistical calculations be terminated after 14 February 1982. Secondly, the period between 14 February and 16 March 1983 was utilized to stress the plant through special operational conditions, and it was undesirable to include this data with that from normal Phase II operation. The statistical summarization of Appendix G-4 documents the data collected during this period.

### Characterization of Finished Waters

Water quality monitoring at three water treatment plants in the Metropolitan Washington Area was conducted between 16 March 1981 and 14 February 1983. Data taken over this entire 23 month period has been statistically characterized in the tables of Appendix H. For comparative purposes, the EEWTP finished water data from the different phases of EEWTP operation have also been included in these tables. Thus, the tabular reports of Appendix H show six monitoring sites:

1. EEWTP Finished Water, Phase IA
2. EEWTP Finished Water, Phase IB
3. EEWTP Finished Water, Phase IIA
4. WTP1 Finished Water
5. WTP2 Finished Water
6. WTP3 Finished Water

The parameters groups used to organize the tables of Appendix H are identical to those used with Appendices F and G. These are discussed more fully in the following section.

### PARAMETER GROUPINGS FOR TABLES

Over 227 different water quality parameters were specifically monitored during this project. For organizational purposes in reporting results, these parameters have been broken into various groups. The different groups and appendices tables where results may be found are summarized below:

## Data Presentation

Physical/aesthetic parameters (except asbestos fibers)	(Table 1 in Appendices F, G, H)
Asbestos fibers	(Table 2 in Appendices F, G, H)
Major cations, anions and nutrients	(Table 3 in Appendices F, G, H)
Trace metals	(Table 4 in Appendices F, G, H)
Radiological parameters	(Table 5 in Appendices F, G, H)
Microbiological parameters (all except viruses and parasites)	(Table 6 in Appendices F, G, H)
Viruses	(Table 7 in Appendices F, G, H)
Parasites	(Table 8 in Appendices F, G, H)
Organic surrogate parameters (TOC and TOX)	(Table 9 in Appendices F, G, H)
Organic chemicals	(Tables 10 to 19 in Appendices F, G, H)
Toxicological parameters	(Tables 20 and 21 in Appendices F, G, H)

Individual parameters comprising the different parameter groups are described in Chapter 4.

For purposes of presentation and discussion, the organic chemicals have been further grouped according to their chemical structure. The groups utilized are indicated in Table 5.2-1. Each of the compounds identified over the course of this project falls into at least one of the structural groupings shown. Some compounds may fall into more than one group, in which case it has been placed into only one of the groups. The list of organic compounds being monitored by the various organic techniques have been presented in Chapter 4. Data for the various compounds at different monitoring sites are then presented for each grouping in Tables 9 to 15 of Appendices F, G, and H. Results for compounds other than those specifically monitored have been compiled for each analytical technique and are presented in Tables 16 to 19 of the appendices.

## GRAPHICAL PRESENTATION

In addition to the tabular statistical summaries previously discussed, the presentation of data in this report is accomplished, in a number of instances, through graphical means as well. The two types of data plots which are most frequently used are briefly described below.

### TIME SERIES PLOTS

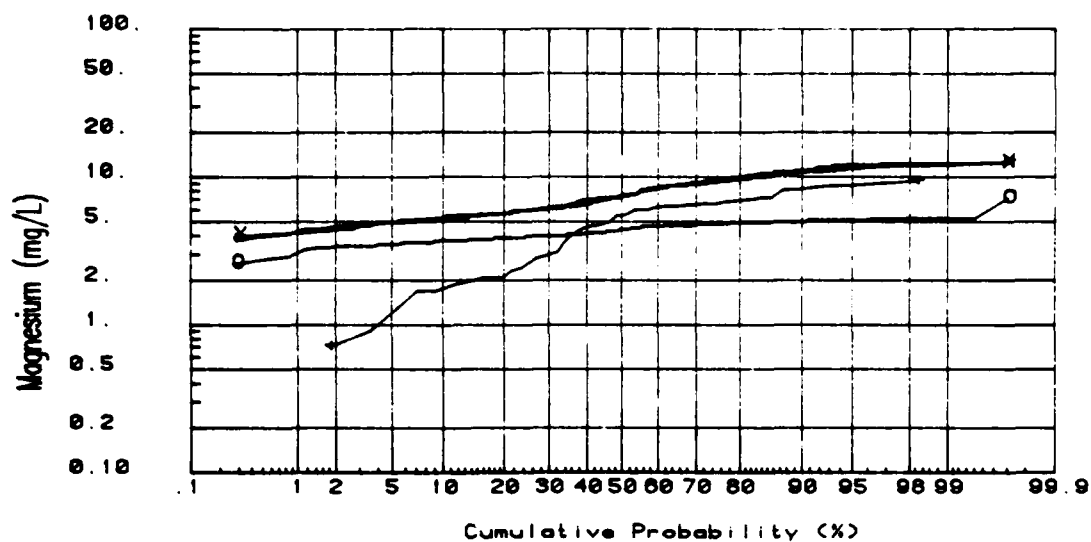
In many instances, it is useful to understand how a parameter varied over time at a given sampling site. In such cases, it is useful to examine a plot of parameter value versus time. Whenever required for data presentation and evaluation, time series plots of this type have been computer generated from the project database. In some cases, the very large number of data points and high variability in the data tend to make such graphs appear "busy" when presented in a limited space. In such cases it may be useful to show only the connecting lines, without the data points, or, in some cases, to show unconnected points. Plots of data types are used in this report.

### FREQUENCY DISTRIBUTION PLOTS

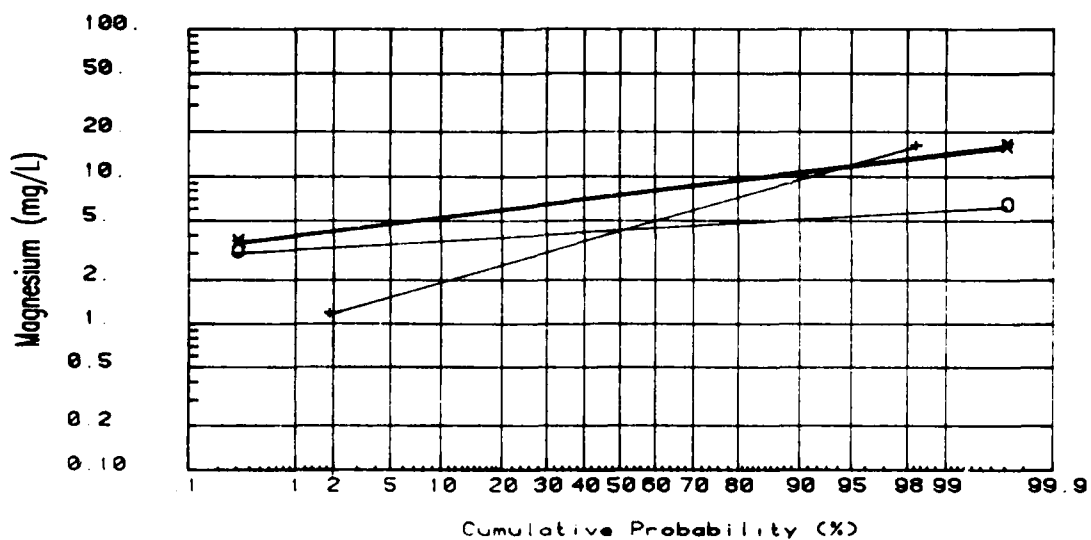
As previously discussed, lognormally distributed data should provide a linear plot when the cumulative distribution function is plotted on lognormal probability graph paper. For plots of this type, data is ranked from highest to lowest values, and value is plotted as a function of the percentage of values that are less than any given plotted value. Figure 5.1-1 of this section illustrates this type of plot. For these plots a straight line may be drawn through the data, based upon the calculated geometric mean and spread factor. This is illustrated in Figure 5.1-2.

In several instances, frequency distribution plots from more than one site are shown on the same graph in order to indicate changes in the distribution of data caused by plant processes or to illustrate the differences between parameter values at different sites. In such cases, inclusion of all the actual data points can tend to make the graphs very difficult to read. For this reason, many of the graphs presented in this report show the connected lines without all the raw data points. This technique is illustrated in Figure 5.2-1(a). Alternatively, it is sometimes useful to plot only the straight lines, as determined drawn from the calculated geometric mean and spread factor. This is illustrated in Figure 5.2-1(b).





(a) Magnesium in EEWTP finished water (Phase IIA) and at three local water treatment plants, connecting lines only.



(b) Magnesium in EEWTP finished water (Phase IIA) and at three local water treatment plants, lines based on computed parameters for lognormal distribution.

TYPICAL CUMULATIVE FREQUENCY DISTRIBUTION PLOTS  
FIGURE 5. 2-1

### SECTION 3

## STATISTICAL TECHNIQUES FOR DATA EVALUATION

### INTRODUCTION

To evaluate finished water quality and the effectiveness of process performance, concentrations of parameters and the effectiveness of their removal were characterized using certain statistical techniques. This made possible the reduction of large quantities of data into a useful form describing both the central tendency of concentrations or removal effectiveness and the variability of these quantities. This section briefly describes the statistical approaches employed during this project.

Concentrations of water quality parameters at monitored locations were generally characterized by calculating statistics such as the arithmetic mean (average), the geometric mean, and the median value. The measures of variability in concentration corresponding to these statistics were also calculated: the standard deviation, the spread factor, and the 90 percentile value.

The median and 90 percentile values are useful for providing an overview of the monitored results; they represent the central and upper 90 percent values of the actual distribution of sample observations. The other statistical parameters (arithmetic and geometric means and variances) are estimated parameters for describing the underlying population of all values, and are appropriate for use when statistically comparing data from different sample populations.

These parameters, and methods used for their determination, have been discussed in Section 1. This section discusses the statistical techniques which have been utilized to evaluate their significance.

### EVALUATION OF FINISHED WATER QUALITY

The two principal statistical tools used to compare and assess water qualities were: (1) hypothesis testing to determine whether concentrations measured in EEWTP finished water were significantly higher or lower than concentrations observed in alternative metropolitan Washington finished waters, and (2) use of a binomial model to estimate the frequency with which Maximum Contaminant Levels set by National Interim Primary Drinking Water Regulations would be exceeded, and the confidence placed in such an estimate. These techniques have been applied to evaluate whether concentrations of potentially harmful water quality parameters are within acceptable levels or have an unacceptably large probability of falling at higher levels.

## HYPOTHESIS TESTING

A basic tool of statistics for examining data is the hypothesis test. In this case, the test is used to determine whether or not the concentration of a water quality parameter in EEWTP finished water is significantly different than the concentration in local finished waters. If the concentration can be demonstrated to be lower in the EEWTP, the parameter is considered not to present a significant problem when compared to other finished waters.

In hypothesis testing, a "null hypothesis" is assumed, and then a calculation is performed to demonstrate that the null hypothesis is incorrect with a certain level of confidence. In the case of this project, it was hypothesized that the EEWTP finished water and a local finished water had the same geometric mean concentration of a parameter. This hypothesis was then tested to prove if it was incorrect, and could be rejected in favor of a conclusion that the parameter was lower in one of the finished waters.

Project hypothesis testing was based on a one sided t-test conducted at the 0.05 significance level. The test was conducted on log-transformed data. When the test is successful, it can be concluded that the EEWTP has a lower geometric mean concentration with a 0.05, or 5 percent, level of significance. This means the probability that the EEWTP actually had an equal or higher mean level than the local treatment plant, was less than five percent. Therefore the tests made in this study have an associated 95 percent level of confidence in having reached the correct conclusion.

A description of the assumptions, calculations, and statistical basis of the hypothesis testing procedure is presented in Appendix B. The geometric mean was selected for hypothesis testing for several reasons, as discussed in Section 1 of this chapter. The procedure includes determination of a value of the "t-statistic" for the sample population. When the value of the t-statistic is greater than a calculated critical value, then the null hypothesis is rejected and the EEWTP finished water is concluded to have had significantly lower concentrations than the alternative. If the t-statistic is calculated to be negative and the absolute value is greater than the critical value, then the null hypothesis is again rejected, but with a conclusion that the alternative had significantly lower concentrations than the EEWTP.

## FREQUENCY CRITERIA AND PROCEDURES

Another statistical procedure used to evaluate water quality in the EEWTP finished water is estimating the frequency with which the finished water is likely to exceed an existing Maximum Contaminant Level (MCL) in the Interim Primary Drinking Water Regulations or the Secondary Drinking Water Regulations. With a few exceptions, the results have shown that the frequency with which MCLs would be exceeded is zero. In some cases, however, the estimate of the frequency with which MCLs would be exceeded is non-zero, and it is necessary to provide a measure of the confidence in this estimate.

The basic model utilized for this form of analysis was the "binomial trial." This model is based on a premise comparable to the concept of drawing straws.

There is some small but finite probability that the MCL will be exceeded when a sample is drawn. The probability can be estimated by drawing several samples and calculating the fraction which show concentrations over the MCL.

When samples include one or more samples in which the MCL is exceeded, the estimate of the frequency with which the MCL would be exceeded in the future is non-zero. This estimate is equal to the fraction of samples with levels above the MCL. A statistical procedure, described in Appendix B, was then employed to estimate the 95 percent confidence interval around this estimate. The confidence interval describes a range of values, for which the probability of including the true value of the frequency is 95 percent.

As an example, three out of 279 samples had concentrations of mercury higher than the NIPDWR MCL in finished water during Phase IA of the monitoring study. Therefore, the estimate for the probability that the goal would be exceeded is  $3/279 = 1.08$  percent. Calculations show that the 95 percent confidence interval around this estimate is 0.223 to 3.08 percent. Thus, the probability that the actual frequency of exceeding the MCL falls in this range is 95 percent.

The binomial model is mainly useful for assessing the confidence with which conclusions about concentrations over the NIPDWR MCL can be drawn from the existing database. Clearly, where fewer samples are drawn, the confidence in an ability to project concentrations is lower, and the confidence interval around the estimate is wider. The procedure is somewhat inferior to the hypothesis test because it does not use quantitative information about the distribution of the actual measured concentrations. Also, it does not predict concentrations or the range of possible concentrations which might have been observed in further sampling.

## EVALUATION OF PROCESS PERFORMANCE

In evaluating process performance of the EEWTP it was often desirable to determine the efficiency of a given process or combination of processes for removing a water quality parameter. The computation utilized was as follows:

$$\% \text{ Removal Efficiency} = 100 (M_i - M_e)/M_i$$

where  $M_i$  and  $M_e$  are the geometric mean influent and effluent concentrations, respectively, for the process(es) under consideration. The geometric mean was utilized for this calculation because it provides a conservative estimate of process performance.

The 95 percent confidence interval for the average removal efficiency was determined from:

$$95\% \text{ CI} = 100 \left[ 1 - \frac{M_e}{M_i} (10^{ts_r}) \right] \text{ to } 100 \left[ 1 - \frac{M_e}{M_i} (10^{-ts_r}) \right]$$

where,

$$s = \left[ \frac{(\log S_i)^2}{m_i} \right] + \left[ \frac{(\log S_e)^2}{m_e} \right]^{1/2}$$

CI = confidence interval

$M_i$  = influent geometric mean

$M_e$  = effluent geometric mean

$m_e$  = number of influent data points above the quantification limit (MDL)

$m_i$  = number of effluent data points above the MDL

$S_i$  = influent spread factor

$S_e$  = effluent spread factor

$t$  = t-statistic based upon a two-tailed 0.05 level of significance with  $m_i + m_e - 1$  degrees of freedom.

As evident from the above equation, a high degree of scatter in either set of data (high spread factor) gives rise to a correspondingly large confidence interval. The CI range decreases with increased sample size.

Calculation of the confidence interval around the estimated percent removal provides a measure of the preciseness of the estimate of removal efficiency and is useful in evaluating the significance of the calculation for drawing conclusions about the process(es).

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## **CHAPTER 6**

### **INFLUENT WATER QUALITY**

A key project objective, as discussed in Chapter 1, was the selection of the appropriate mix of treated wastewater and Potomac River estuary water, which would best simulate the water quality expected to occur in the estuary during drought conditions. This chapter presents the results of this selection, and a comparison between the projected water quality to that observed during the two years of EEWTP operation.

The first section of this chapter describes the numerical modeling undertaken to select an appropriate blend of nitrified effluent from the Blue Plains Wastewater Treatment Plant and Potomac River estuary water to simulate projected water quality in the estuary during future drought conditions.

The second section describes selection of the appropriate blend ratio of these two source waters.

The third section presents the characterization of the water quality in the two source waters and blended influent over the two years of EEWTP operation. For selected parameters, the contribution of each source to the blended influent is also presented.

The fourth section compares the EEWTP water quality to the projected levels of those water quality parameters modeled in the Potomac River estuary during future drought conditions. Revised maximum projected concentrations of these parameters were calculated based on two years monitoring of the Blue Plains nitrified effluent. In addition, this chapter provides an overview of the EEWTP influent water quality during the different phases of operation.

## **SECTION 1**

### **PROJECTED WATER QUALITY FOR AN ESTUARY WATER TREATMENT PLANT**

This section describes the modeling efforts used to project the influent water quality expected in the estuary near the site of a possible future estuary water treatment plant.

As discussed in Chapter 1, an estuary water treatment plant using water from the Potomac River estuary near Washington, D.C. was proposed to meet a portion of the projected future water supply deficits in the MWA. For purposes of modeling projected influent quality, two sites for the proposed estuary water treatment plant were investigated. One proposed site was located at Chain Bridge, near the head of the Potomac estuary, and the other site was located at Potomac Park, approximately six miles downstream from Chain Bridge. Numerical water quality modeling was used to project expected raw water quality for an estuary water treatment plant at either of these two locations.

#### **EARLY MODELING EFFORTS**

Prior to this project, several modeling studies had been conducted to estimate water quality conditions in the Potomac River estuary under numerous hydrologic scenarios. In these studies, two very different water quality models were used.

A brief review of the results of these key studies is presented below as background for a discussion of the extension of the modeling work conducted in this study.

#### **PRELIMINARY MODELING**

In 1973, a study was completed to provide a preliminary assessment of the feasibility of using water from the Potomac estuary to supplement the MWA water supply under drought conditions (Hydroscience, 1973). At the time of the study, the design capacity of the proposed estuary water treatment plant was not fixed. The study estimated the worst water quality at the head of the estuary near Chain Bridge for a number of minimum stream flows dependent on three alternative reservoir construction programs and on wastewater treatment plant recycle rates.

The following parameters were modeled: total dissolved solids (TDS), chloride, coliforms, total phosphorus, biochemical oxygen demand (BOD<sub>5</sub>), organic-nitrogen (N), NO<sub>3</sub>-N, NO<sub>2</sub>-N, NH<sub>3</sub>-N, algal-N and dissolved oxygen. The model was a steady-state, one-dimensional, segmented estuary model, with a single dispersion constant to represent tidal influences. Nonpoint sources were not included. Increases in concentrations of the water quality parameters due to



## Projected Water Quality For an Estuary Water Treatment Plant

municipal use were modeled by assuming a fixed concentration increase through each municipal use cycle. This "use increment" reflected concentration changes due to water treatment, municipal and industrial use, wastewater collection, and wastewater treatment in the MWA.

With the assumptions used in the study, the results indicated that TDS levels were low enough to permit the use of estuary water for municipal consumption in low flow periods. The study indicated, however, that because of uncertainties regarding the health effects of trace contaminants, a demonstration of technical feasibility was required. One major limitation in the model was the use of 1966 hydrologic conditions rather than 1930 hydrologic conditions (a more intense, longer lasting drought) as the boundary conditions for modeling.

Table 6.1-1 compares the projected adjusted low stream flows at Little Falls to the adjusted historic low streamflows. This comparison shows that for drought periods of fourteen days or less, hydrologic conditions from the year ending 31 March 1967 compare closely with the minimum flows for a recurrence interval of once per hundred years. However, for drought periods between 30 and 183 days, hydrologic conditions from the year ending 31 March 1931 provide a closer simulation of the hundred year drought. Based on this limitation, and the assumption of steady-state conditions using a small number of channel segments to represent the estuary, these preliminary results were not sufficient for selecting the appropriate blend ratio for the EEWTP influent.

### REVISED MODELING FOR TESTING PROGRAM

As part of the development of a testing program for the operation of the EEWTP, a more detailed analysis of the estuary system was conducted using a different model and revised boundary conditions (GKY, 1979). These revised modeling efforts were designed to investigate the present variability of concentrations of water quality parameters in the estuary, the influence of this variability on the desired frequency of sample collection during EEWTP operation, and the projected concentrations of TDS and other conservative parameters at the site of a future estuary water treatment plant intake under various drought scenarios.

For the revised modeling efforts, the Environmental Protection Agency's Dynamic Estuary Model (DEM) (EPA, 1979) was used to simulate estuary water quality under both future drought conditions and present average flow conditions. For the drought simulation, parameters were assumed to be conservative, and included TDS, total phosphorus, major anions and cations, nitrate, ammonia, and several trace metals. The concept of the "use increment" was again used to simulate the concentration increases for a given water quality parameter due to water treatment, municipal use, wastewater collection and wastewater treatment.

The following hydrologic boundary conditions (i.e., inflows to and withdrawals from the portion of the estuary being modeled) were used:

**Projected Water Quality  
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**TABLE 6.1-1  
COMPARISON OF PROJECTED ADJUSTED LOW STREAMFLOWS AT LITTLE FALLS, MD  
TO HISTORIC LOW ADJUSTED STREAMFLOW**

No. of Consecutive Days	Projected Low Stream Flows <sup>1</sup> (cfs)			Historic Low Stream Flows <sup>2</sup>		
	100 yr. Recurrence Interval <sup>3</sup>	50 yr. Recurrence Interval	20 yr. Recurrence Interval	10 yr. Recurrence Interval	Lowest Mean Stream Flow (cfs)	Year
1	600	677	809	945	601	1967 <sup>4</sup>
3	630	710	847	987	612	1967
7	654	736	875	1020	626	1967
14	711	791	929	1074	686	1967
30	809	896	1046	1206	844	1931
60	845	959	1160	1376	907	1931
90	957	1081	1306	1549	908	1931
120	1089	1242	1515	1811	933	1931
183	1447	1645	2000	2389	1160	1931

1. Based on period of record Water Year (WY) 1931 - partial 1983, projections based on Log-Pearson Type III statistics; values listed are flows which are not exceeded during given interval. (Information from NAWDEX, U.S. Geological Survey, Reston, VA, April 1983.)
2. Based on period of record WY 1931 - partial 1983.
3. Corresponds to (1/P), where P = probability that flow will not exceed given value during a given interval in any one year.
4. Defined as year ending March 31 (e.g., 1967 represents 1 April 1966 to 31 March 1967).

**Projected Water Quality  
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1. Inflow to the estuary from the Potomac River was varied monthly over a 90-day drought interval.
2. Upstream flows in the Potomac River were varied between 600 and 1,300 MGD, with water demands decreasing from 750 to 600 MGD during the simulated period.
3. The operating capacity of the full-scale estuary water treatment plant was fixed at 200 MGD for the simulation.

Thus, the hydrologic boundary conditions, which affect the movement of water in the estuary and, in turn, the transport of water quality parameters, were varied only three times in the modeled time period.

In addition to projecting future water quality in the estuary, the model was used to estimate present average summer and winter water quality in the estuary near the site of the EEWTP, in order to judge the expected variability in estuary water quality and the blended influent during EEWTP operation.

Based on the DEM results, a blend ratio of one part nitrified effluent and two parts estuary water was initially recommended as the appropriate blend for the EEWTP influent.

**MODELING UPDATE FOR SELECTION OF  
EEWTP INFLUENT MIX RATIO**

The major limitation of the modeling efforts described above was the use of monthly average inflows to the estuary, which restricted the ability of the model to respond to severe low flow periods. Thus, re-evaluation of the behavior of the estuary system under future low flow conditions was necessary prior to selection of the appropriate blend ratio for the EEWTP. In addition, a sensitivity analysis of model predictions to extreme hydrologic events was needed to evaluate the likelihood of extreme values of selected water quality parameters.

After consideration of previous model applications, the DEM model was chosen as most suitable for further use in estuary modeling. The major advantage of the DEM is that variable inflows and wasteloads to the estuary may be considered. Also, the DEM represents the estuary in smaller segments than do simpler steady-state models, and should better predict the hydraulics and transport of conservative parameters in the estuary. Details of the DEM are presented in Appendix C.

Accurate characterization of non-conservative parameters in the estuary is not as certain, however, because of the many natural processes controlling the fate of these parameters. Equations for many of these natural processes can be incorporated into the DEM, however, the kinetic parameters in these equations must be evaluated for the specific situation, (i.e., model calibration) in order to make accurate predictions. This study was limited to those parameters which could be considered conservative. These limitations were expanded to include some non-conservative parameters which undergo slow degradation or

**Projected Water Quality  
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transformation in the estuary, relative to the time frame of the modeling period. For these parameters (e.g.,  $\text{NH}_3$ ,  $\text{NO}_3$ ), the model predictions are less accurate and serve as "worst-case" estimates.

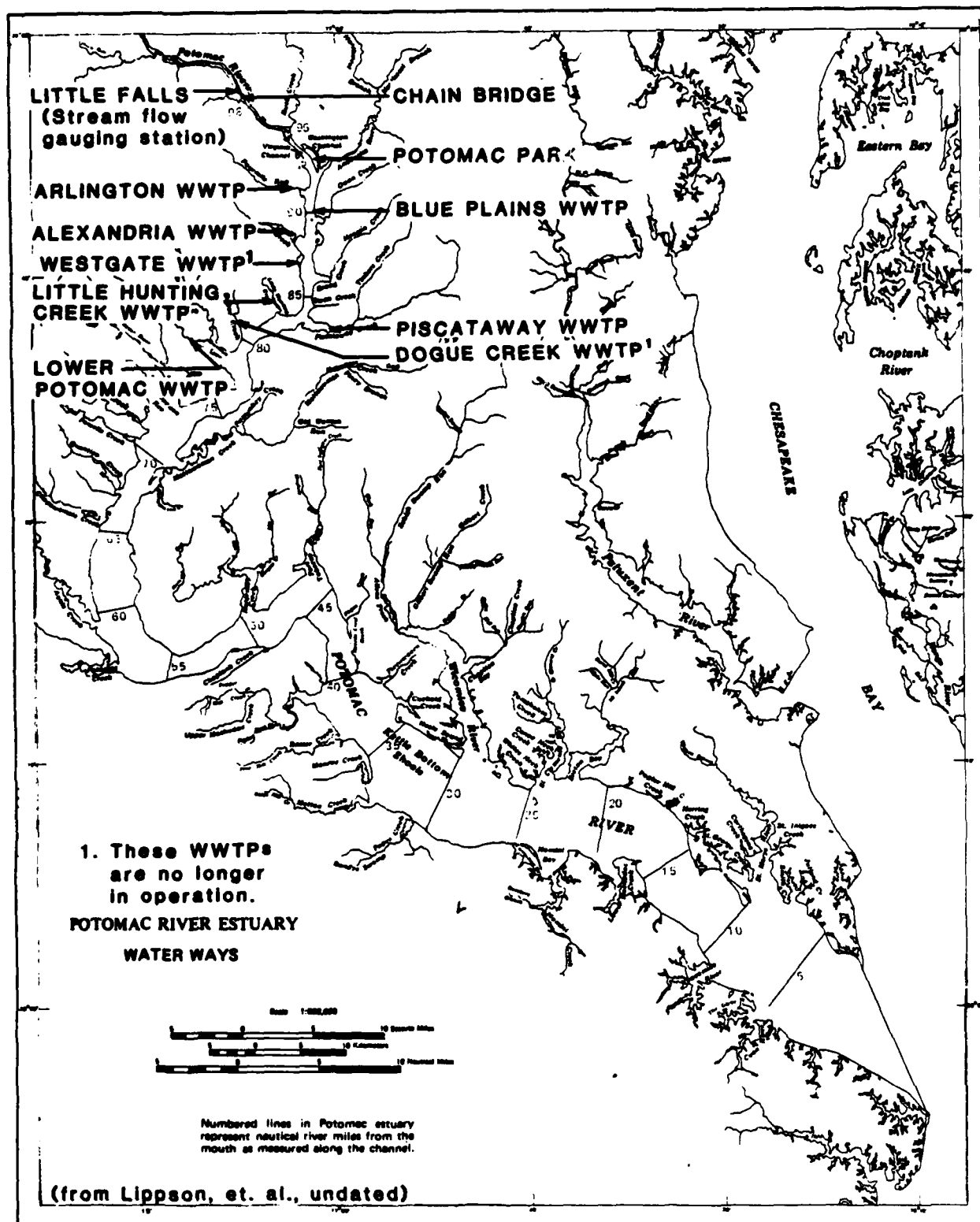
The DEM consists of two components. The first is a hydrodynamic model which describes the tidal variations of water movement throughout the estuary. The second component is a water quality model which describes the transport, decay, and transformation of parameters in the estuary. The mathematical equations used to describe natural processes in each component of the DEM are referenced to as a "link-node" network, which represents the geometrical configuration of the estuary. The "link-node" network is laid out for a particular application in order to provide information on water movement and/or water quality at critical points within the estuary.

To maintain required numerical accuracy, the hydraulic component of the DEM required a ninety second time step (i.e., unacceptable numerical errors would have been carried through the calculations had the movement of water in the estuary been calculated at an interval greater than every ninety seconds). Thus, to model six months of the hydraulics of the Potomac River estuary, the DEM required a considerable amount of computer time. Available resources for this study, therefore, limited consideration of alternative scenarios to only a few runs of the hydrologic component of the DEM.

The results of the hydraulic component of the DEM for a given scenario in the Potomac River estuary were stored and used as input for a subsequent run of the water quality component. To preserve the same numerical accuracy as the hydrodynamic component, a time step of thirty minutes was used for the water quality component.

The principal objectives of the updated modeling efforts were to verify previous projections for concentrations of conservative parameters, and to determine the sensitivity of those predictions to alternative boundary conditions, including variable use increments, alternative withdrawal sites for the potential estuary water treatment plant, and extreme value situations. The alternative scenarios modeled are summarized in Table 6.1-2.

The hydrodynamic component of the DEM was used to predict water movement in the Potomac estuary. A six month drought period, from 16 June to 15 December, was modeled. In contrast to the earlier application of the DEM described above, hydrologic boundary conditions used in the computer model were varied daily instead of monthly in the time period modeled in this study. This was felt to provide a better resolution of actual water movement within the estuary. Figure 6.1-1 shows the location of the head of the estuary, near Chain Bridge, relative to the two locations considered for an estuary water treatment plant.



**LOCATION MAP OF  
POTOMAC RIVER ESTUARY  
FIGURE 6. 1-1**

Projected Water Quality  
For an Estuary Water Treatment Plant

TABLE 6.1-2  
SUMMARY OF POTOMAC ESTUARY MODELING SCENARIOS  
IN THIS STUDY

Estuary WTP Intake Location	Hydrologic Conditions	Parameter Modeled
Chain Bridge	July - December 1930	TDS <sup>1</sup>
Chain Bridge	July - December 1930	NH <sub>3</sub> <sup>2</sup>
Potomac Park	July - December 1930	TDS
Potomac Park	July - December 1930	NH <sub>3</sub>
Potomac Park	No fresh water inflow at Chain Bridge after 25 August of model year	TDS

1. The behavior of TDS, a conservative parameter, was used to estimate the behavior of other parameters relative to their background concentrations and use increments.
2. NH<sub>3</sub> was chosen to model the effects of various lengths of breakdown of the nitrification process at Blue Plains WWTP.

Fresh water inflow to the estuary was calculated using the observed flows at the Little Falls gauging station during Water Years 1930 and 1931 (i.e., July to December 1930) which reflect the upstream withdrawal of approximately 300 cfs (194 MGD) for water demands at that time. As the projected upstream water demands above Little Falls are 750 cfs (484 MGD), an additional 450 cfs (290 MGD) was subtracted from the observed 1930 flows to simulate future conditions. A table of the streamflows used is provided in Appendix C. Freshwater inflow from the Anacostia was held constant at 20 cfs (13 MGD).

Total municipal water demand was held constant at 1550 cfs (1000 MGD) during the six month simulation period for all scenarios modeled. The estuary water treatment plant was assumed to begin operation on 14 August, maintaining a constant withdrawal of 310 cfs (200 MGD) for the remainder of the modeling period. The water deficit between the fixed demand of 1550 cfs and estuary plant production of 0 cfs prior to 14 August and 310 cfs after 14 August was assumed to be satisfied by other supplies.

The water quality component of the DEM was used to predict levels of total dissolved solids (TDS) throughout the estuary, which were then related to levels of other conservative water quality parameters. Rather than perform a separate modeling run to determine initial TDS levels in the estuary, an initial estimate was obtained using the results of previous modeling efforts (GKY, 1979). Freshwater inflow to the estuary was held constant at 550 cfs (355 MGD) for the first month of the six month modeling period to reach a steady-state condition.

## Projected Water Quality For an Estuary Water Treatment Plant

Sources of water quality parameters were the fresh water inflow to the estuary and the discharges of eight local wastewater treatment plants (WWTPs). Of these WWTPs, Blue Plains was the largest, handling over seventy percent of the MWA wastewater flow. Withdrawals of municipal water from the estuary treatment plant and other local sources were delayed for four days prior to discharge into the estuary through the WWTPs. A ten percent consumptive loss of water withdrawn from the Potomac was assumed. Increases in the levels of water quality parameters in the remaining ninety percent of water withdrawn from the Potomac were reflected in the "use increment." A schematic of the structure of the hydrodynamic and water quality components of the DEM is presented in Figure 6.1-2.

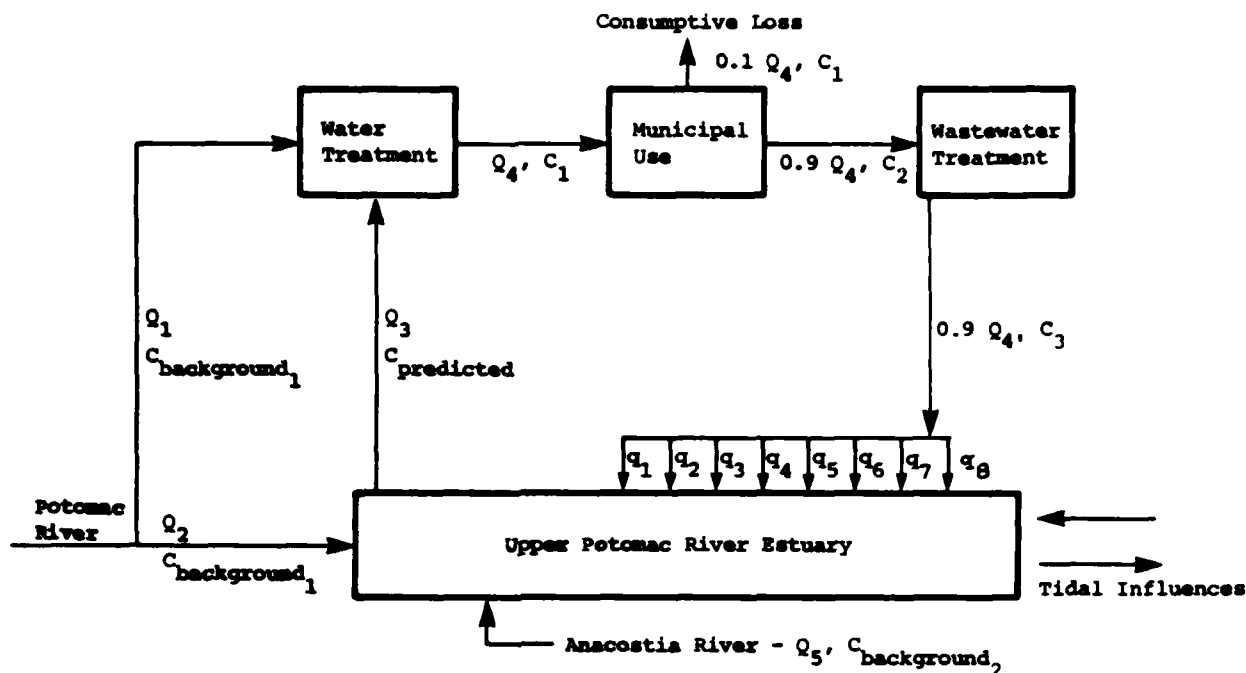
### BASE CONDITION SCENARIO

Each of the scenarios modeled was characterized by the degree of flowby (i.e., fresh water inflow to the estuary) at Chain Bridge, and the treatment efficiency of the wastewater treatment plants. The base condition scenario assumed 1930 freshwater inflow into the Potomac River estuary, modified for future upstream diversions as described above. The water treatment plant intake was located at Chain Bridge, near the head of the estuary. The WWTPs were assumed to operate with no removal of TDS, which is representative of typical wastewater treatment plant operation.

TDS was selected as the parameter of interest for the base condition scenario in order to determine the level of TDS contributed by tidal action from the seaward boundary. It was found that there was a negligible contribution of TDS from tidal action under the hydrologic conditions used. This result indicated that the concentration buildup of TDS in the estuary was due only to increases caused by municipal use, discharge of treated wastewater to the estuary, and subsequent mixing and transport. Thus, the concentration buildup of any conservative water quality parameter, irrespective of its concentration at the seaward boundary, could be calculated by simply scaling to the concentration buildup of TDS.

The projected daily concentration variations at a Chain Bridge water intake are plotted in Figure 6.1-3 for the last ninety days of the base condition scenario. TDS levels range from the background concentration of 180 mg/L to a high of 447 mg/L, based on a municipal use increment of 400 mg/L.

An additional run of the DEM water quality component with a TDS use increment of 200 mg/L showed that the TDS concentration in the estuary, above background levels in the Potomac River, at any time was proportional to the "use increment" used in the run. This relationship allowed the use of Equation 1 to describe the concentration of any conservative parameter given its background concentration in the Potomac River and its "use increment." Note that this equation simply scales the concentration buildup in the estuary to the buildup observed for TDS.



### LEGEND

- $C_{background_1}$  = Concentration in Potomac River at Little Falls, MD
- $C_{background_2}$  = Concentration in Anacostia River
- $C_{predicted}$  = Concentration predicted using DEM at Estuary WTP Intake
- $C_1$  = Concentration following water treatment
- $C_2$  = Concentration following municipal and industrial use
- $C_3$  = Concentration following wastewater collection and treatment
- $Q_1$  = Flow diverted at Little Falls, MD
- $Q_2$  = Unadjusted stream flow measured at Little Falls, MD gauging station (ie - freshwater inflow to estuary)
- $Q_3$  = Flow taken from estuary at future Estuary WTP Intake
- $Q_4$  = Flow of treated drinking water for M&A
- $Q_5$  = Flow into estuary from Anacostia River
- $q_1$  = Fraction of treated wastewater for M&A discharged into estuary through WTP<sub>1</sub>

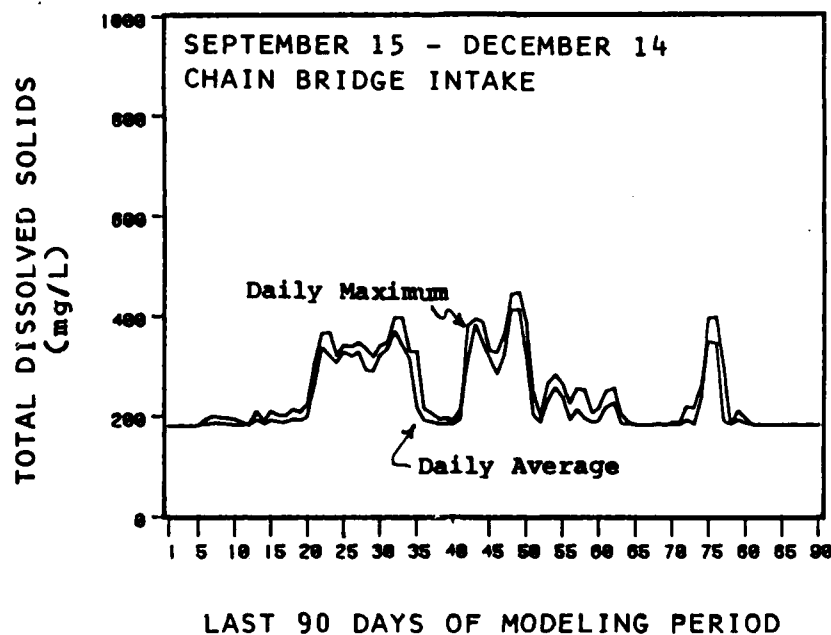
$$\sum_{i=1}^9 q_i = 0.9 Q_4$$

$$\text{"Use Increment"} = C_3 - C_{background}$$

**SCHEMATIC ILLUSTRATING HYDROLOGIC AND  
CHEMICAL MASS BALANCES IN  
UPPER POTOMAC RIVER ESTUARY USED IN  
THE EPA DYNAMIC ESTUARY MODEL**

**FIGURE 6. 1-2**





**PROJECTED DAILY AVERAGE  
AND MAXIMUM TDS CONCENTRATIONS  
AT ESTUARY WTP CHAIN BRIDGE INTAKE  
UNDER FUTURE DROUGHT CONDITIONS**

**FIGURE 6. 1-3**

Projected Water Quality  
For an Estuary Water Treatment Plant

$$C_{\max} = C_{\text{back}} + C_{\text{UI}} \left( \frac{TDS_{\max} - TDS_{\text{back}}}{TDS_{\text{UI}}} \right) \quad (1)$$

where  $C_{\max}$  = maximum concentration of a conservative parameter in the estuary  
 $C_{\text{back}}$  = background concentration of parameter in the Potomac River  
 $C_{\text{UI}}$  = municipal "use increment" for parameter

Table 6.1-3 presents the background concentrations, use increments and maximum projected concentrations of water quality parameters included in the initial DEM modeling efforts. Background concentrations for these water quality parameters were obtained from observed water quality in the Potomac River. Two columns of figures are listed under the heading "use increments". The left hand column represents the use increments used prior to start-up of the EEWTP to select a blend of Potomac estuary and Blue Plains nitrified effluent. These original use increments were obtained by taking the difference between the background and the average concentration observed in the Blue Plains secondary effluent based on data available in 1981.

The revised use increments were obtained by taking the difference between the background concentration as listed in the table and the Blue Plains nitrified effluent arithmetic mean concentration as measured during the two years of EEWTP operation. For several water quality parameters, revised use increments could not be calculated because the background concentration was higher than the arithmetic mean concentration in the Blue Plains nitrified effluent.

The last two columns in Table 6.1-3 list the maximum projected concentrations, which represent the peak concentration reached on a single day during the 120-day modeling of estuary water quality under drought conditions.

The original maximum projected concentrations were used at the start-up of the EEWTP as the basis for selection of an appropriate blend ratio for the plant influent. This is discussed in more detail in Section 2 of this chapter. The Revised Maximum Projected Concentrations (RMPCs) are discussed in Sections 3 and 4 of this chapter in comparing the degree to which the EEWTP blended influent simulated the projected water quality under future drought conditions.

#### LOCATION OF ESTUARY WATER TREATMENT PLANT INTAKE AT POTOMAC PARK

For this scenario, the DEM was used in essentially the same way as for the base condition run, with the exception that the intake for the estuary water treatment plant was assumed to be at Potomac Park instead of at Chain Bridge. Potomac Park was considered to be the lowest point in the estuary which would be suitable as a possible site for an estuary WTP. High TDS levels, and thus high levels of other water quality parameters, would preclude the feasibility of sites below Potomac Park. Flowby and wastewater treatment plant efficiency were unchanged from the base condition run. In effect, this scenario places the plant intake closer to the Blue Plains outfall, and creates a zone of "fresh" water at the head of the estuary.

Projected Water Quality  
For an Estuary Water Treatment Plant

TABLE 6.1-3  
MAXIMUM PROJECTED WATER QUALITY PARAMETER CONCENTRATIONS  
AT CHAIN BRIDGE INTAKE  
(2030 WATER DEMANDS, JULY - DECEMBER  
1930 HYDROLOGIC CONDITIONS)

Parameter	Background Concentration (mg/L)	Use Increments		Maximum Projected Concentrations	
		1981 Original (mg/L)	1983 Revised <sup>a</sup> (mg/L)	1981 Original (mg/L)	1983 Revised (mg/L)
<b>Major Cations, Anions, and Nutrients</b>					
Total Dissolved Solids	180	400	195	447	310
Calcium	26.9	30	29.2	47	46.4
Hardness (as CaCO <sub>3</sub> )	91	100	83.1	158	146.5
Magnesium	5.9	6.0	2.4	9.9	7.5
Potassium	2.3	7.0	6.4	7.0	6.6
Sodium	8.0	85	35.9	65	32.0
Alkalinity (as CaCO <sub>3</sub> )	63	100	--- <sup>b</sup>	130	63 <sup>c</sup>
Chloride	9.4	107	61.2	81	50.3
Nitrogen-NO <sub>3</sub> -N	1.27	6.7	11.4 <sup>d</sup>	5.7	8.9 <sup>d</sup>
Nitrogen-NH <sub>3</sub> -N	0.06	1.9	0.5	1.3	0.4
Total Phosphorus-P	0.09	0.31	0.33 <sup>e</sup>	0.30	0.31 <sup>e</sup>
Sulfate	27.2	43	54.2	56	62.2
<b>Trace Metals</b>					
Aluminum	0.83	0.2	--- <sup>b</sup>	0.96	0.83 <sup>c</sup>
Cadmium	0	0.1	0.0017 <sup>f</sup>	0.07	0.0001 <sup>f</sup>
Chromium	0.012	0.17	--- <sup>b</sup>	0.13	0.012 <sup>c</sup>
Copper	0.006	0.10	0.0087 <sup>f</sup>	0.07	0.0087 <sup>f</sup>
Iron	1.36	0.1	0.2553	1.4	1.53
Lead	0.002	0.1	0.0002	0.07	0.002
Manganese	0.096	0.2	0.147	0.23	0.194
Mercury	0	0.0014	0.0003	0.001	0.0002
Nickel	0.010	0.05	--- <sup>b</sup>	0.04	0.01 <sup>c</sup>
Silver	0	0.02	0.0011	0.01	0.0007
Strontium	0.22	0.2	NME	0.35	0.22 <sup>c</sup>
Zinc	0.026	0.04	0.0024	0.05	0.028

- a. Calculated using reported background concentrations and Blue Plains Nitrified Effluent arithmetic mean values measured during EEWTP operation (reported in Appendix Table F-4).
- b. Background concentration greater than Blue Plains Nitrified Effluent arithmetic mean; thus, these parameters could not be calculated.
- c. Background concentration listed as "worst case" estimate.
- d. Nitrogen-Nitrate+ Nitrite concentrations used.
- e. Orthophosphate concentration used.
- f. Concentrations as measured by AAS, as opposed to ICAP, used.
- g. Not measured in this study.

## Projected Water Quality For an Estuary Water Treatment Plant

TDS concentration variations are plotted in Figure 6.1-4 for the last 90 days of the simulated drought period. Figure 6.1-4 shows that TDS levels rise gradually to a maximum near the end of the period, and then decline due to the rapidly increasing freshwater inflow to the estuary at Chain Bridge. This scenario more closely resembles a simple recycle system, due to the reduced influence of freshwater inflow on estuary concentrations. With this scenario, predicted maximum concentrations of conservative parameters are greater than those with the base condition scenario by a factor of 1.2.

### LOCATION OF ESTUARY WATER TREATMENT PLANT INTAKE AT POTOMAC PARK AND NO FRESHWATER INFLOW

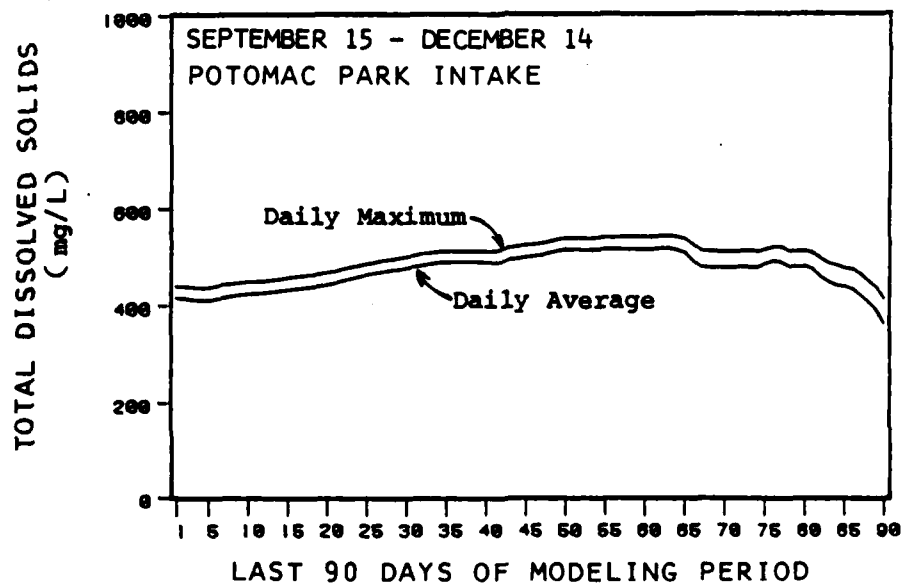
In this scenario, the estuary water treatment plant intake was located at Potomac Park, as in the previous scenario, and freshwater inflow at Chain Bridge was artificially set to zero beginning on 25 August of the model year (i.e., the day of minimum river flow). This scenario may represent a sudden interruption in outside water supply which requires overuse of the Potomac River, or any other situation in which flow at Chain Bridge is restricted for a substantial period of time. The resulting TDS levels shown in Figure 6.1-5 indicate the extreme buildup of TDS during a period of no freshwater inflow. With this scenario, predicted maximum concentrations of conservative parameters are greater than those with the base condition scenario by a factor of 1.7.

### BREAKDOWN OF NITRIFICATION FACILITIES

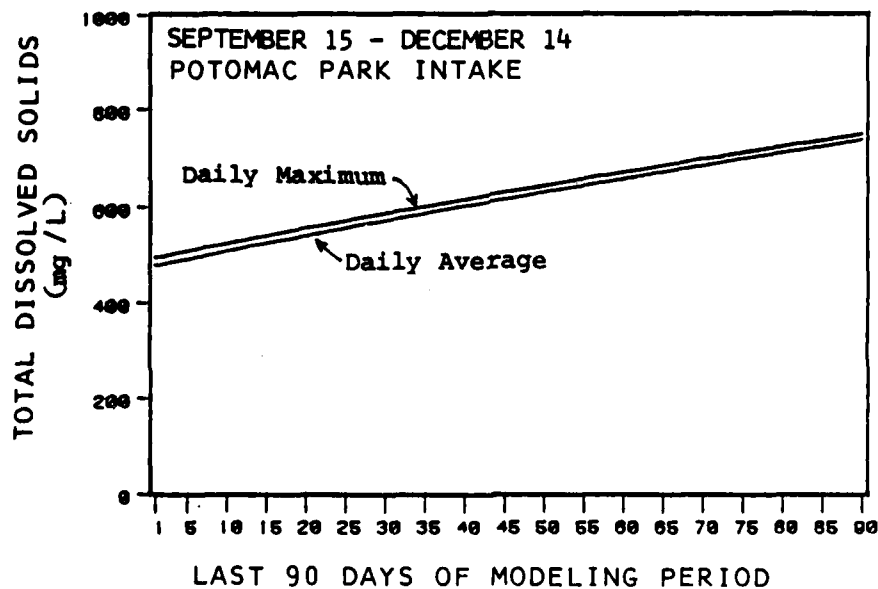
This scenario was designed to investigate the substantial release of a parameter to the estuary from one or more wastewater treatment plants due to a partial breakdown of treatment processes. The parameter of interest for this scenario was  $\text{NH}_3\text{-N}$ , with a background concentration of 1 mg/L and a use increment of 10 mg/L. Previous water quality monitoring in the estuary between 1975 and 1980 measured levels of  $\text{NH}_3\text{-N}$  ranging up to 2 mg/L-N. It was assumed that a properly functioning nitrification wastewater treatment plant would convert  $\text{NH}_3$  to  $\text{NO}_3$  prior to discharge in the estuary. The effluent concentration of  $\text{NH}_3\text{-N}$  was assumed to be 1 mg/L.  $\text{NH}_3$  was assumed to behave as a conservative parameter, although nitrification in the estuary would be expected to reduce  $\text{NH}_3$  concentrations during summer conditions. This scenario thus represents a worst case estimation of  $\text{NH}_3$  concentrations in the estuary.

To evaluate the levels of  $\text{NH}_3$  in the estuary for various periods of nitrification breakdown, the water quality component of the DEM was repeatedly run for breakdown intervals ranging from 5 to 110 days. Freshwater inflow to the estuary was the same as in the base condition scenario, and separate runs were completed for the two alternative plant intake location.

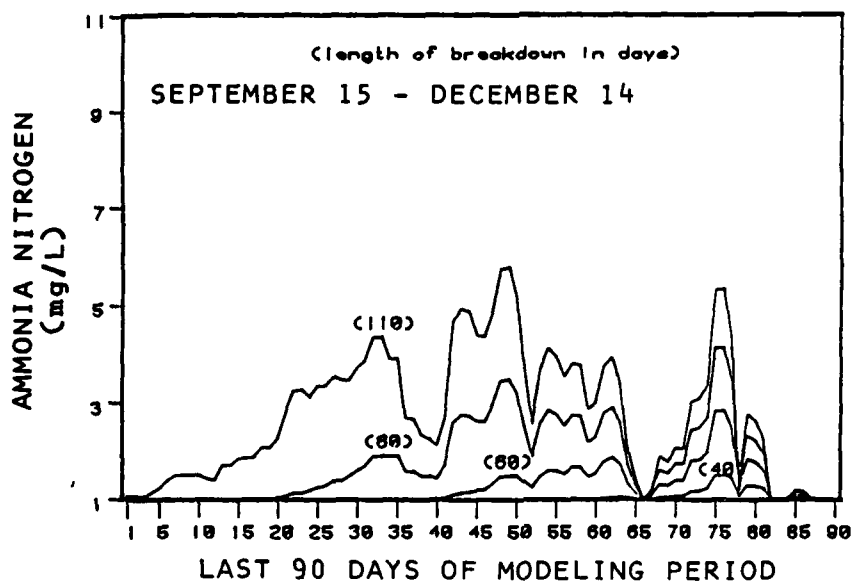
Results for this set of runs are presented in Figures 6.1-6 and 6.1-7, for the two plant intake locations. The figures indicate that the time of maximum concentration varies with the length of the breakdown, due primarily to the variation in flowby. The location of the intake at Chain Bridge, compared to



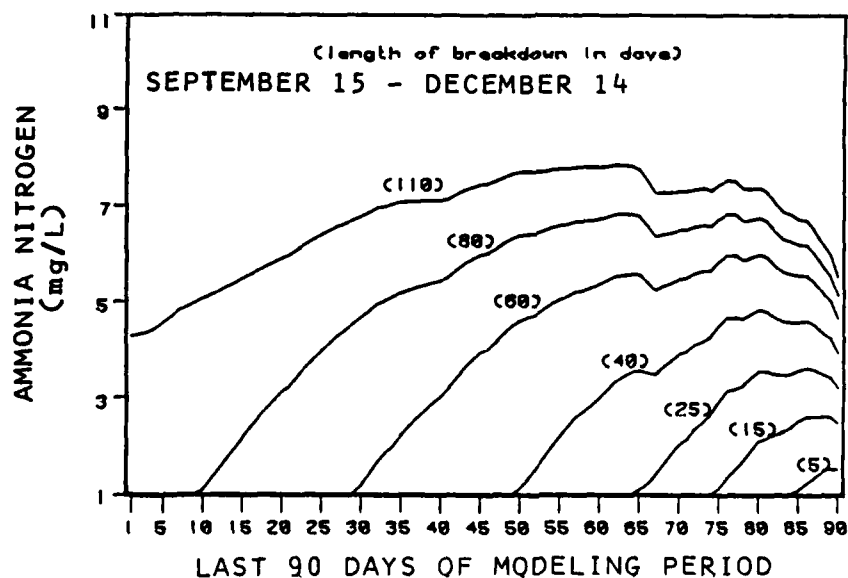
**PROJECTED DAILY AVERAGE AND  
MAXIMUM TDS CONCENTRATIONS AT  
ESTUARY WTP CHAIN BRIDGE INTAKE  
FIGURE 6. 1-4**



**PROJECTED DAILY AVERAGE AND  
MAXIMUM TDS CONCENTRATIONS AT  
ESTUARY WTP CHAIN BRIDGE INTAKE  
NO FRESHWATER INFLOW AT CHAIN BRIDGE  
FIGURE 6. 1-5**



**MAXIMUM DAILY AMMONIA NITROGEN CONCENTRATIONS  
AT ESTUARY WTP CHAIN BRIDGE INTAKE  
EFFECT OF BLUE PLAINS WWTP  
NITRIFICATION BREAKDOWN  
FIGURE 6. 1-6**



**MAXIMUM DAILY AMMONIA NITROGEN CONCENTRATIONS  
AT ESTUARY WTP POTOMAC PARK INTAKE  
EFFECT OF BLUE PLAINS WWTP  
NITRIFICATION BREAKDOWN  
FIGURE 6. 1-7**

## Projected Water Quality For an Estuary Water Treatment Plant

Potomac Park, serves to delay the effects of a breakdown for about forty days. Increases in ammonia concentration then proceed at the same rate for both locations.

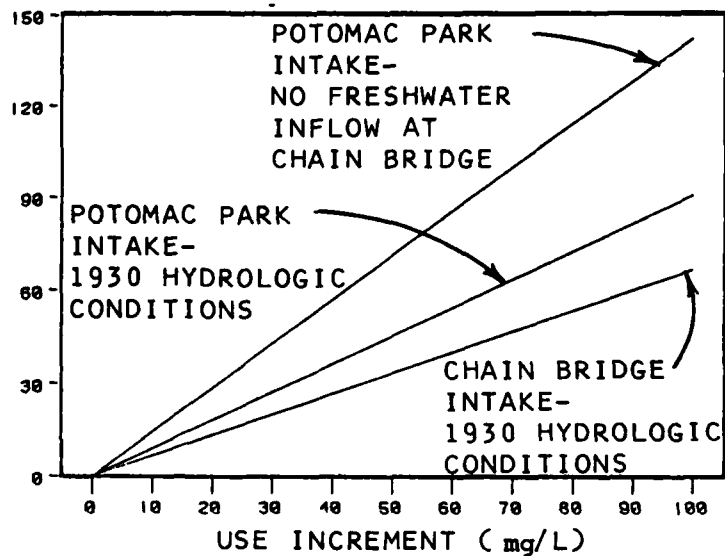
### SUMMARY

To develop a basis for selecting the appropriate blend of source waters for the EEWTP influent, studies using the Environmental Protection Agency's Dynamic Estuary Model with drought period hydrologic conditions based on observed streamflows in 1930 were conducted. Selected water quality parameters were modeled under several scenarios consisting of alternative locations for an estuary water treatment plant intake, alternative freshwater inflows to the estuary at Chain Bridge, and breakdowns in the efficiency of nitrification at the Blue Plains WWTP.

The model results indicated that concentration increases of conservative parameters during a drought period in the Potomac estuary were due to municipal use and subsequent mixing and transport in the estuary. For a given scenario, the two characteristics of a water quality parameter used to describe its concentration at any time in the estuary are the background concentration in the Potomac River and the use increment. The use increment describes concentration increases in water removed from the estuary due to water treatment, municipal use, wastewater collection and wastewater treatment.

For the scenarios considered in this study, Figure 6.1-8 summarizes the relationship between use increment and the maximum estuarine concentration above the background concentration. For example, the projected maximum concentration at Chain Bridge of a conservative water quality parameter with a use increment of approximately 60 mg/L, under 1930 hydrologic conditions, is 38 mg/L above the background concentration. Similar calculations were used to obtain the RMPCs presented in Table 6.1-3.

INCREMENTAL ESTUARY CONCENTRATION  
ABOVE POTOMAC RIVER BACKGROUND  
(MAXIMUM PREDICTED ONE-DAY  
CONCENTRATION, mg/L)



**SUMMARY OF MAXIMUM PREDICTED POTOMAC ESTUARY  
CONCENTRATIONS OF CONSERVATIVE PARAMETERS  
UNDER FUTURE DROUGHT CONDITIONS  
FIGURE 6.1-8**



## **SECTION 2**

### **SELECTION OF INFLUENT BLEND**

#### **INTRODUCTION**

Because of the limitations in the use of the DEM and other uncertainties regarding projections of water quality fifty years into the future, selection of the appropriate influent blend for EEWTP operation was expected to be difficult. Within these constraints, however, the estuary modeling results were compared with the most recent water quality data characterizing the influent sources as of March 1981 to provide a basis for selection of the influent blend. This section describes the basis for selection, and presents the expected water quality of the selected blend based on water quality data available at the initiation of the project.

#### **LIMITATIONS ON SELECTION PROCEDURE**

The ideal strategy for selection of an appropriate blend of the two influent streams would have been to predict the frequency distribution of major water quality parameters of potential health significance in the estuary under future drought conditions, and then compare these distributions with the expected distribution of each parameter in the two influent streams to the EEWTP. Unfortunately, this could not be accomplished due to several factors:

1. Inability of the DEM to predict the fate of most parameters of health significance.
2. Uncertainties in selecting the appropriate model boundary conditions.
3. Limited water quality data for the EEWTP source waters at the time the selection was made in March 1981.

#### **SELECTION OF MIX RATIO**

Because levels of many water quality parameters of potential health significance could not be projected using the DEM, the quantitative basis of the selection procedure used to determine the appropriate mix ratio was based primarily on projected levels of conservative parameters which could be modeled. For other parameters, a comparison was made between expected EEWTP influent water quality levels for a specified blend ratio and suggested finished water quality goals. These goals were based on standards promulgated or proposed by state, federal, and international organizations as of March 1981. This procedure provided a framework for determining if the EEWTP treatment processes would be expected to produce a water of acceptable quality for

## Selection of Influent Blend

consumption given the influent water quality for the several scenarios evaluated.

Water quality data available at the initiation of the project characterizing the two influent sources are summarized in Tables 6.2-1 and 6.2-2. Table 6.2-1 contains data on most of the water quality parameters modeled using the DEM and for which maximum projected concentrations in the estuary were calculated. Table 6.2-2 summarizes the limited data available in March 1981 for selected water quality parameters not modeled using the DEM and/or of potential health significance.

A comparison of mean or 90 percentile values in Table 6.1-3 immediately illustrates the dilemma in selecting an appropriate EEWTP influent blend. For example, using Blue Plains nitrified effluent as the sole source water results in an EEWTP influent which matches the projected maximum TDS level, but far exceeds the maximum projected nitrate level. On the other hand, using the Potomac River estuary water as the sole source water results in an EEWTP influent with lower levels of naturally occurring organics, as measured by TOC, and other trace organics than would be expected in the estuary during severe drought conditions.

Table 6.2-3 illustrates these tradeoffs for five modeled water quality parameters, showing the ratio of the maximum projected concentrations of these parameters to the expected concentration calculated from source water quality data as a function of blend ratio. The table shows that an equal blend ratio, or one part nitrified effluent to one part estuary water, appears to provide a blended influent with a reasonable match to model predictions. This is discussed for each parameter group in more detail below.

### ANTICIPATED EEWTP INFLUENT WATER QUALITY WITH AN EQUAL MIX RATIO

Table 6.2-4 provides a comparison of maximum projected values for several parameters at Chain Bridge with 1930 hydrologic conditions using the DEM model and the estimated values for an equal ratio of nitrified effluent and estuary water.

The anticipated characteristics of several groups of water quality parameters in the EEWTP blended influent using an equal blend are discussed below. An evaluation of these March 1981 projections relative to actual observations during EEWTP operation is presented in Section 4.

### PARTICULATE CONTAMINANTS

During the trial start-up period at the EEWTP, turbidity levels using an equal blend ratio were within the range observed in a majority of river drinking water sources. However, the anticipated levels of turbidity calculated from available source water quality data were lower than the observed trial start-up levels. This is due to the unusually low turbidities observed in the estuary during the U.S. Army Corps of Engineers estuary baseline study. Anticipated levels of another particulate contaminant, asbestos fibers, were uncertain because only one sample had been taken in the two source waters prior to March 1981.

# Selection of Influent Blend

TABLE 6.2-1  
SUMMARY OF AVAILABLE MONITORING DATA  
EEWTP SOURCE WATERS  
(as of March 1981)

		Estuary Baseline Data Near Blue Plains (Dec 1975 - Sep 1979)		Blue Plains Nitrified Effluent (Aug 1980 - Mar 1981)	
<u>Parameter</u>	<u>Units</u>	<u>Arith. Mean</u>	<u>90 Percentile</u>	<u>Arith. Mean</u>	<u>90 Percentile</u>
<u>Microbiological</u>					
Total Coliform	MPN/ 100 ml	4x10 <sup>4</sup>	3 x 10 <sup>5</sup>	5x10 <sup>5a</sup>	---
<u>Inorganics</u>					
TDS	mg/L	215	293	413	440
Cl	mg/L	18	—	120	—
Total P (as P)	mg/L - P	.04	—	1.2	1.8
NH <sub>3</sub> (as N)	mg/L - N	.92	2.5	2.0	5.8
NO <sub>3</sub> (as N)	mg/L - N	.88	1.8	8.0	11.0
TKN (as N)	mg/L - N	—	—	4.0	9.0
Cd	mg/L	ND	—	.0017 <sup>b</sup>	---
Cu	mg/L	.006	.008	.015	—
Cr (total)	mg/L	.002	—	.0056	—
Ni	mg/L	.003	.005	.0066	—
Pb	mg/L	.002	—	.0048	—
Zn	mg/L	.015	.032	.062	—
As	mg/L	.002	.003		
<u>Organics</u>					
BOD <sub>5</sub> (total)	mg/L	—	—	11.6	22
BOD <sub>5</sub> (soluble)	mg/L	—	—	1.7	2.5
COD	mg/L	16	26	—	—

a. Based on average of five samples

b. Metals for Blue Plains based on nine daily grab samples taken 2/81

# Selection of Influent Blend

TABLE 6.2-2

SUMMARY OF AVAILABLE MONITORING DATA IN  
EEWTP SOURCE WATERS FOR PARAMETERS NOT MODELED  
(AS OF MARCH 1981)

<u>Parameter</u>	<u>Units</u>	<u>Blue Plains Nitrified Effluent</u>	<u>Potomac Estuary</u>
Turbidity <sup>1</sup>	NTU	—	18+14
TSS <sup>2</sup>	mg/L	17+17	—
TOC <sup>3</sup>	mg/L - C	10	7
TOX <sup>4</sup>	µg/L - Cl	250	160
Sum of Purge- able Organic Compounds <sup>5</sup>	µg/L	25 - 32	0.9 - 4.0
Asbestos <sup>6</sup>	MFL	4.9	36.9
Radiological Gross Alpha <sup>6</sup>	pCi/L	0+3.8	0.5+4.2
Gross Beta <sup>6</sup>	pCi/L	11.5+30.1	17.8+30.3
Algae <sup>1</sup>	(no./ml)	—	1,500

1. U.S. Army Corps of Engineers Potomac River estuary baseline study, 1975 - 1979.
2. From Blue Plains monitoring data, August 1980 - February 1981 (daily composite samples and influent monitoring).
3. Influent monitoring, December 1980 - February 1981.
4. Average of three samples, February 1981.
5. Range of two samples (13 compounds quantified, 3 detected but below quantification limit of 0.1 µg/L).
6. Single sample, MFL = million fibers per liter

# Selection of Influent Blend

TABLE 6.2-3

RATIO OF EXPECTED 90 PERCENTILE CONCENTRATIONS  
USING AVAILABLE SOURCE WATER MONITORING DATA TO DEM  
BASE SCENARIO MAXIMUM PROJECTED CONCENTRATIONS

Parameter	Percent Nitrified Effluent:	0	25	50	75	100
	Percent Estuary Water:	100	75	50	25	0
	Blend Ratio:	0:1	1:3	1:1	3:1	1:0
TDS		0.66	0.75	0.82	0.90	0.98
Cl <sup>1</sup>		0.22	0.54	0.85	1.17	1.48
NO <sub>3</sub> -N		0.32	0.72	1.12	1.53	1.93
NH <sub>3</sub> -N		1.92	2.56	3.19	3.83	4.46
Pb <sup>1</sup>		0.03	0.04	0.05	0.07	0.07

1. Arithmetic mean concentrations in source waters used for these parameters.

# Selection of Influent Blend

TABLE 6.2-4

COMPARISON OF MAXIMUM PROJECTED CONCENTRATIONS OF  
WATER QUALITY PARAMETERS AT CHAIN BRIDGE WITH  
ESTIMATED EEWTP INFLUENT USING EQUAL BLEND RATIO  
(AS OF MARCH 1981)

Parameter	JMM Maximum Projected Concentration <sup>2</sup> (1981)	Statistic Used <sup>3</sup>	Estimated Value <sup>1</sup> Equal Blend Ratio Concentration <sup>2</sup>
<u>Particulate Contaminants</u>			
Turbidity (NTU)	NM <sup>4</sup>	Mean	15
Asbestos (MFL)	NM	Single Value	22
<u>Inorganic Parameters</u>			
TDS	447	90%	366
Cl	81	Mean	69
Cd	0.07	Mean	0.008
Cr (total)	0.13	Mean	0.004
Ni	0.04	Mean	0.005
Pb	0.07	Mean	0.003
Zn	0.05	Mean	0.04
Total-P	0.3	Mean	0.6
NH <sub>3</sub> -N	1.3	90%	4.2
NO <sub>3</sub> -N	5.7	90%	6.4
<u>Microbiological Parameters</u>			
Total Coliform	NM	Mean	2x10 <sup>5</sup> MPN/100 ml
Algae (no./ml)	NM	Max	750
<u>Organic Parameters</u>			
TOC	NM	Mean	8.5
Purgeable Organics (µg/L)	NM	(Range)	12-20
TOX <sup>5</sup> (µg/L-Cl)	NM	Mean	200

1. Values obtained from Tables 6.2-1 and 6.2-2.
2. Unit in mg/L except where noted.
3. When available, 90 percentile statistic used for comparison with maximum projected value.
4. NM = Not Modeled.
5. TOX generated in treatment process.

## Selection of Influent Blend

### INORGANIC PARAMETERS

Using an equal blend ratio, the maximum projected concentrations of the inorganic parameters TDS, Cl, and trace metals could not be achieved. For the nutrients total phosphorus,  $\text{NH}_3\text{-N}$ , and  $\text{NO}_3\text{-N}$ , it was anticipated that the blended influent would exceed the maximum projected concentrations. Thus, based on comparisons of maximum projected concentrations to anticipated concentrations with an equal blend ratio, the selected blend ratio would be conservative for the nutrients (i.e., exceeded projected DEM concentrations), but would still provide about 80 percent of the projected levels of major anions and cations.

### MICROBIOLOGICAL PARAMETERS

Total coliform levels were not modeled using the DEM. The anticipated level of total coliforms in the EEWTP influent was approximately  $2 \times 10^5$  MPN/100 ml. This anticipated value exceeded the recommended level of total coliforms of  $2 \times 10^4$ /100 ml in water sources suitable for public water supplies using a treatment process of coagulation, sedimentation, filtration, and disinfection (NAS, NAE, 1972). As shown in Table 6.2-4, very high bacterial kills of roughly six orders of magnitude would be required to meet the proposed goal of 0.1 MPN/100 ml as discussed in Chapter 1, Section 5. It was assumed, however, that the proposed goal could be reached using the advanced treatment available at the EEWTP.

Anticipated algae levels in the blended influent were not unusual for surface supplies. Thus, for these two microbiological parameters, the equal blend ratio was judged to be conservative with respect to maximum levels which might occur under future drought conditions.

### ORGANIC PARAMETERS

The anticipated levels of TOC, volatile organic compounds (other than THMs), and TOX in the EEWTP blended influent using an equal blend could not be quantitatively evaluated because these parameters were not modeled using the DEM. However, assuming the parameter to be conservative, a rough comparison for projected and anticipated levels of TOX can be made using the results of the DEM described in Section 1. Using the scenario of an intake at Chain Bridge and 1930 hydrologic conditions, a negligible background concentration above Little Falls, and a use increment of  $118.7 \mu\text{g/L-Cl}$  (corresponding to the arithmetic mean of the Blue Plains nitrified effluent), a projected maximum concentration of  $95 \mu\text{g/L-Cl}$  is obtained from Figure 6.1-8. This concentration is lower than the expected TOX levels of about  $200 \mu\text{g/L-Cl}$  with the equal blend. Thus, this blend would be conservative with respect to this potentially important parameter of health concern.

### SUMMARY

As shown in Table 6.2-3, it was anticipated that the equal blend would provide a blended influent quality that would not exactly match any single maximum

## Selection of Influent Blend

projected value of the inorganic parameters modeled using the DEM. Compared to the previous recommendation for a smaller proportion of nitrified effluent, the equal blend was projected to provide higher levels of trace organics, including TOX, trace metals, total organic carbon, and probably enteric viruses. A larger proportion of nitrified effluent was not acceptable, however, because of high  $\text{NO}_3$  levels, and because the estuary water provided levels of particulate contaminants, notably asbestos fibers, and algae, not present in the nitrified effluent.

It was apparent from the projected water quality data that any influent blend was not likely to match more than one target level of a water quality parameter. The selected mix thus represents a compromise between maximum projected levels of parameters of marginal health significance (e.g., TDS, Cl, total P,  $\text{NH}_3$ ) using the DEM, and unspecified levels for parameters of known or probable health significance (e.g., certain trace metals, certain trace organics, TOX, and asbestos fibers).



### SECTION 3

#### EEWTP INFLUENT WATER QUALITY MONITORING MARCH 1981 - MARCH 1983

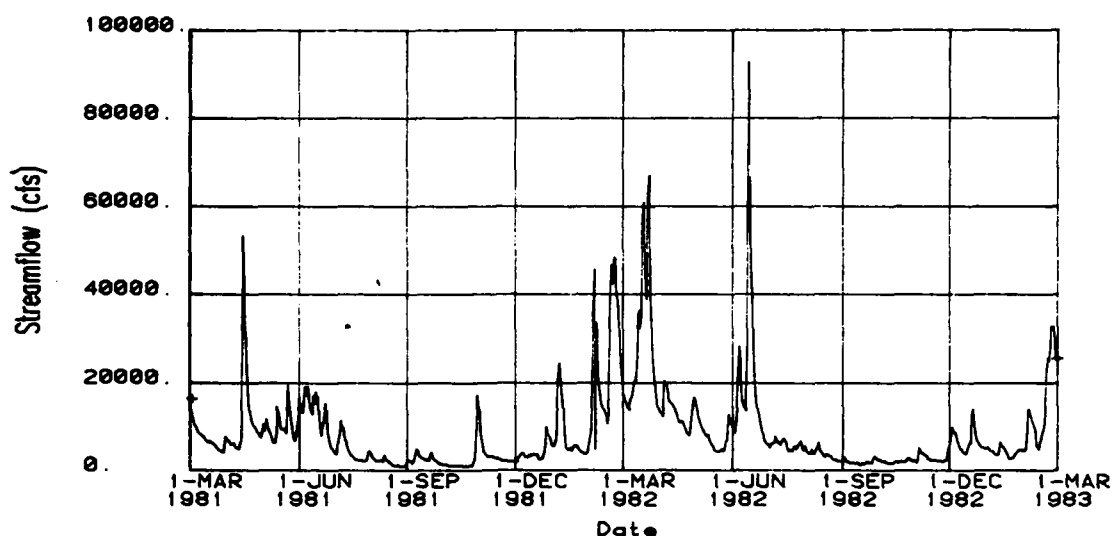
A complete statistical summary for all water quality parameters monitored in the two EEWTP source waters and blended influent is found in Appendix F. This section presents a statistical characterization of those water quality parameters which were found to have an impact on process performance, as discussed in Chapters 7 and 8, or were found to be of special interest when compared to levels in finished waters from local water treatment plants in the MWA, as presented in Chapter 9.

#### HYDROLOGIC CHARACTERIZATION OF POTOMAC RIVER AND ANACOSTIA RIVER STREAMFLOWS

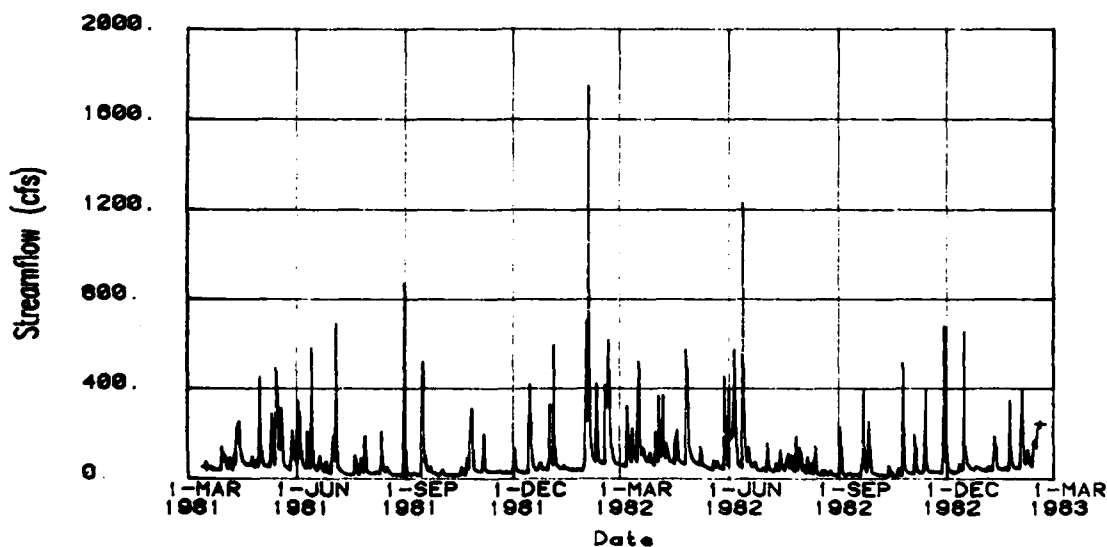
During the two-year operating period of the EEWTP, the water quantity and quality in the estuary varied dramatically by season, as was anticipated. During the first year, flows were considerably below normal, while during the second year of operation, above normal streamflows were observed. These varying hydrologic conditions of the freshwater inflow to the estuary affected the quality of the blended influent at the EEWTP, and were the cause of many extreme events with respect to levels of certain water quality parameters, most notably particulate contaminants i.e., total suspended solids (turbidity, asbestos), and some trace metals. This section presents a brief overview of the hydrologic conditions in the Potomac River during the period of operation of the EEWTP and the impact of these conditions on the levels of selected water quality parameters.

Streamflows in the Potomac River at the Little Falls, MD gauging station, which is the last gauging station before the Potomac River enters the estuary, are shown in Figure 6.3-1 for the period of EEWTP operation. The streamflows measured at this gauging station represented an upstream drainage area of 11,560 square miles. The streamflows plotted have been adjusted to include water diverted for drinking water and other purposes above the Little Falls gauging station. Figure 6.3-2 shows the streamflows in the two branches of the Anacostia River during the two years of EEWTP operation. These two figures indicate the quantity of fresh water flowing into the head of the estuary, which was expected to affect the water quality of the EEWTP blended influent.

In general, normal rainfall in the MWA is approximately 39 inches per year (Leo Harrison, U.S. National Weather Service, personal communication, 1983). The rainfall throughout 1981 was approximately seven to eight inches below normal. The rainfall during January through August 1982 was above normal, but the rainfall during August through December was below normal. The net rainfall for 1982 was approximately two to four inches above normal.



**STREAMFLOW IN POTOMAC RIVER AT  
LITTLE FALLS, MD GAUGING STATION DURING  
TWO YEARS OF EEWTP OPERATION  
FIGURE 6. 3-1**



**SUM OF STREAMFLOWS FOR ANACOSTIA RIVER AT  
HYATTSVILLE, MD AND RIVERDALE, MD, GAUGING STATIONS  
DURING TWO YEARS OF EEWTP OPERATION  
FIGURE 6. 3-2**

EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983

PHYSICAL/AESTHETIC PARAMETERS

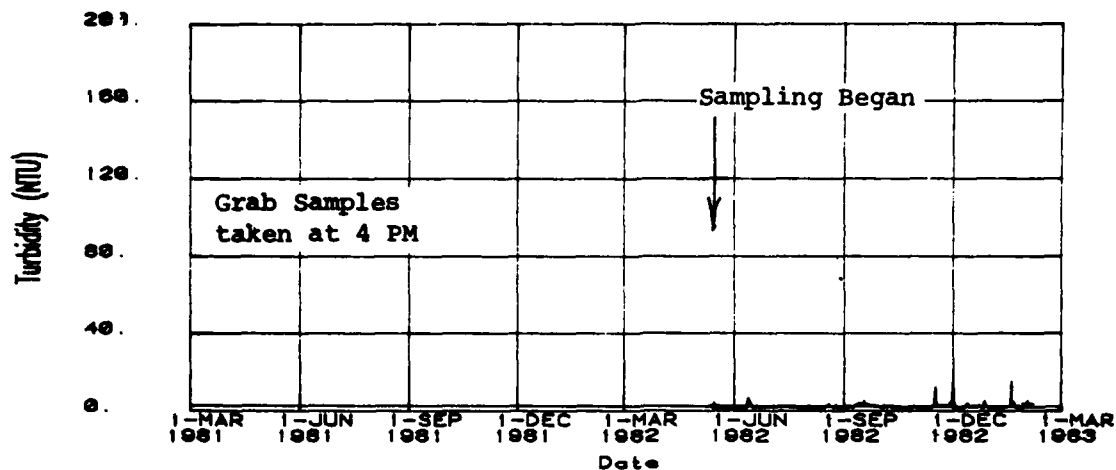
Turbidity in EEWTP source waters and blended influent is shown in Figures 6.3-3(a), (b), and (c) for the two years of EEWTP operation. The MCL for turbidity of 1 NTU, set by the NIPDWR, is shown on Figure 6.3-3(c). Sampling programs for this and other quality parameters which were initiated after 15 March 1981 are indicated on these figures.

As shown by these figures, the Blue Plains nitrified effluent made little contribution to turbidity in the blended influent. A visual comparison between turbidity in the blended influent and streamflow in the Potomac River, as shown in Figure 6.3-1, shows a strong correlation between high streamflow and high turbidity levels, as expected. Turbidity levels in the blended influent exceeded the MCL, as expected.

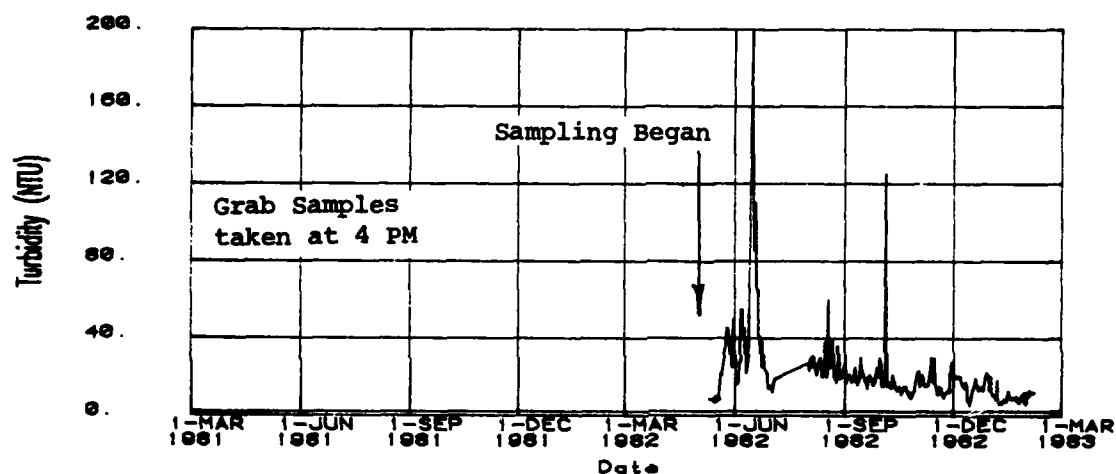
Apparent color in the EEWTP source waters and blended influent is shown in Figures 6.3-4 (a), (b) and (c). Color levels were relatively high (>30 CU) at all sample sites, and exceeded the SMCL of 15 CU in the blended influent throughout the period of EEWTP operation. Color was highly variable and showed no clear seasonal trends.

Temperature in the EEWTP source waters and blended influent is shown in Figure 6.3-5(a), (b), and (c). Seasonal variations are very strong, as illustrated in all three figures. The use of the Blue Plains nitrified effluent in the EEWTP blended influent produced higher temperatures in the winter and lower temperatures in the summer than would be observed in a full-scale estuary water treatment plant. Thus, while the temperatures observed in the EEWTP blended influent ranged from approximately 7 to 28°C, the range of temperatures which would be observed in a full-scale estuary treatment plant would be closer to that observed in the estuary source water, approximately 0 to 28°C.

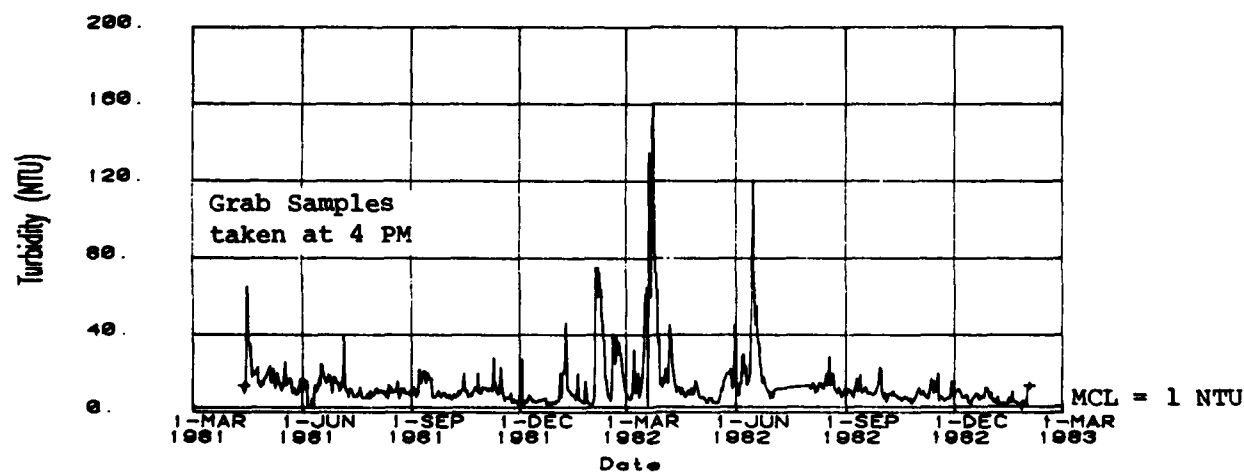
Table 6.3-1 lists the arithmetic mean levels of physical/aesthetic parameters measured in the EEWTP blend tank. The table also shows the relative contributions of each source water to the EEWTP blended influent. As anticipated, the major portion of particulate contaminants were contributed by the estuary source water. However, MBAS, a contaminant expected in treated wastewaters, was mainly contributed by the nitrified effluent. Other parameters in this group were present at equal levels in the two sources.



(a). Blue Plains Nitrified Effluent

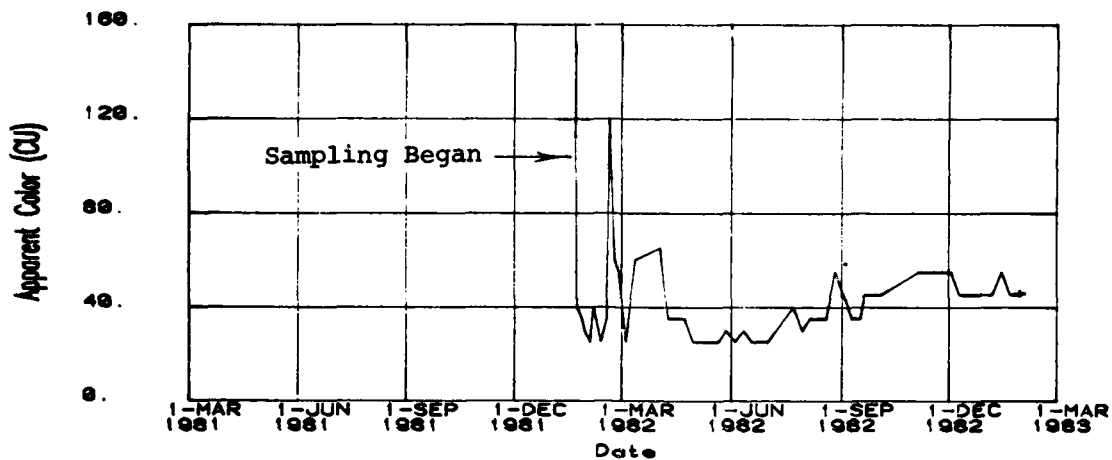


(b). Potomac Estuary Water

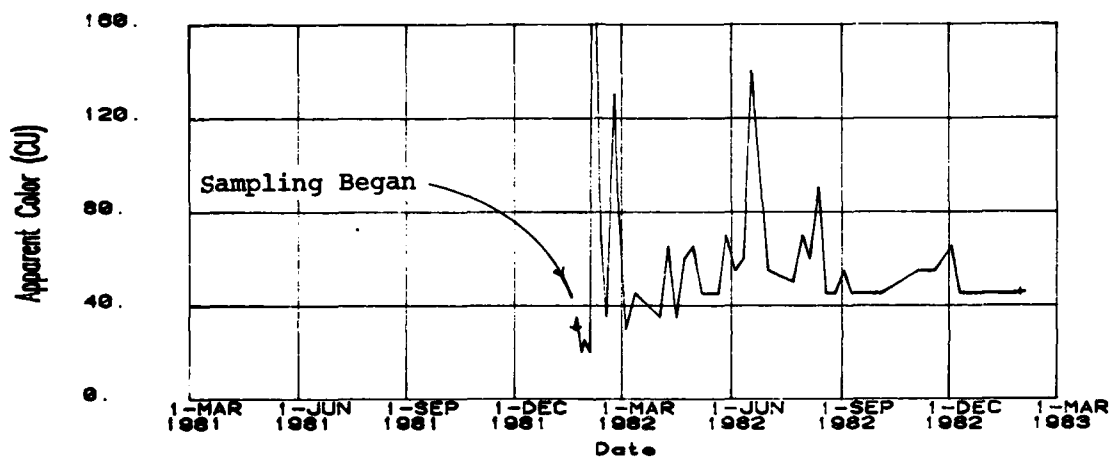


(c). EEWTP Blended Influent

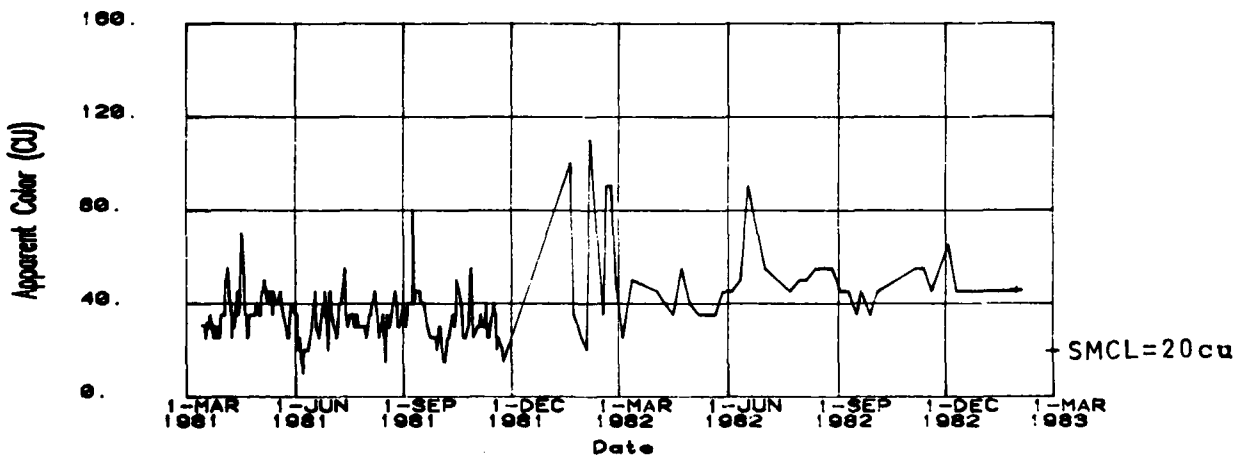
**TURBIDITY  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-3**



(a). Blue Plains Nitrified Effluent

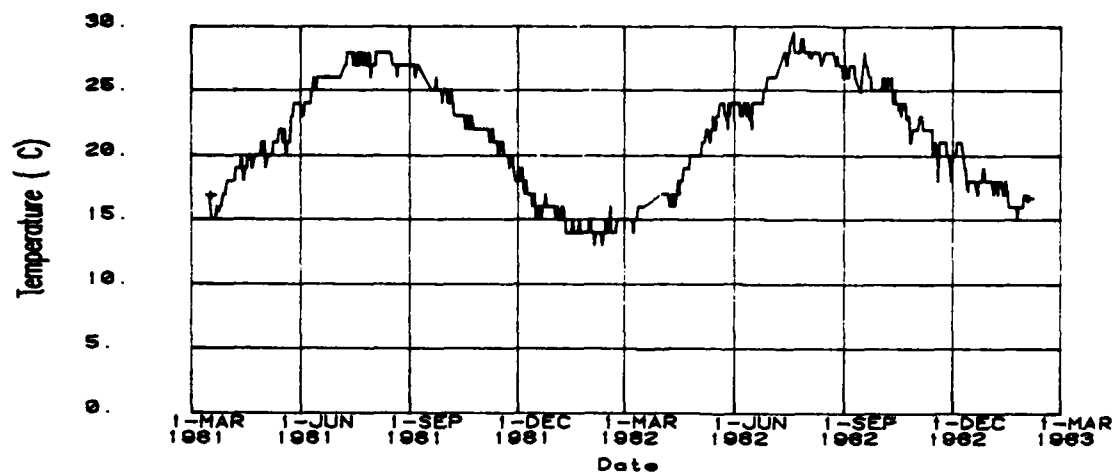


(b). Potomac Estuary Water

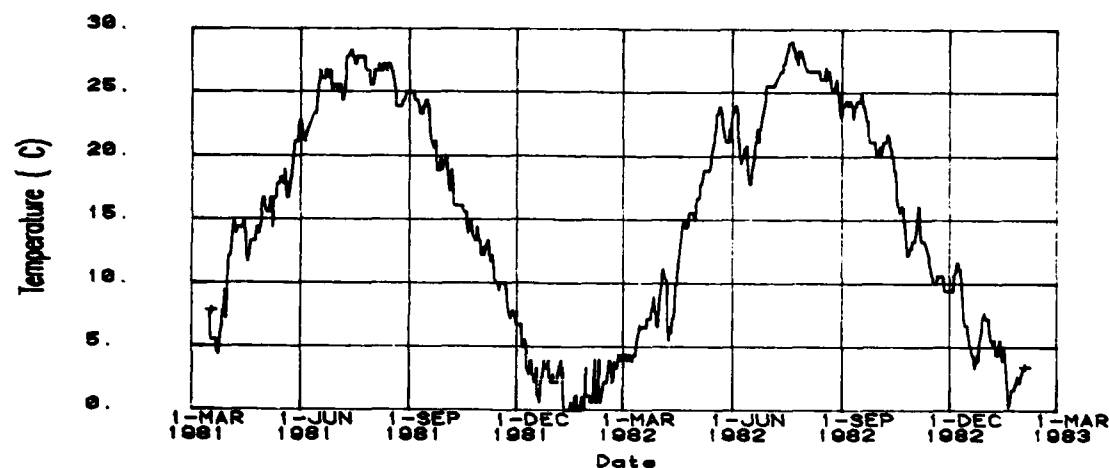


(c). EEWTP Blended Influent

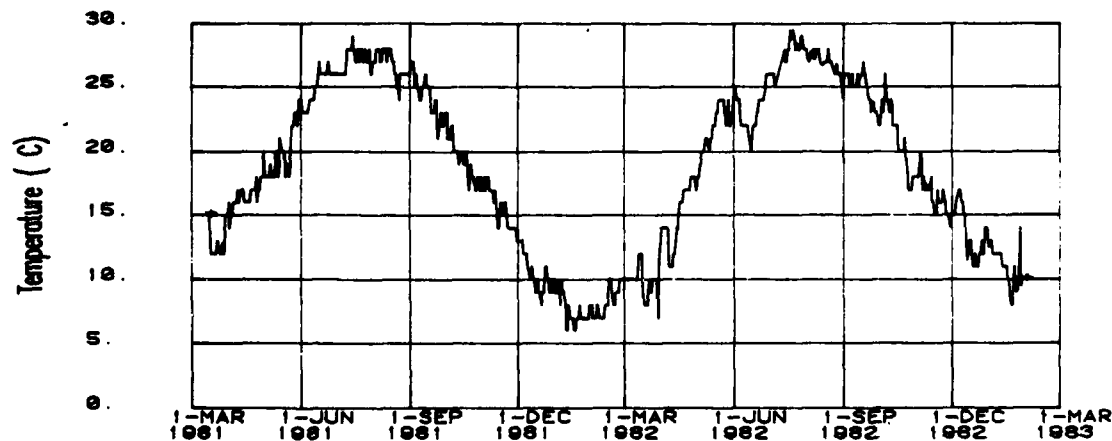
**APPARENT COLOR  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-4**



(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). EEWTP Blended Influent

**TEMPERATURE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-5**

EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983

TABLE 6.3-1  
SOURCE CONTRIBUTIONS  
PHYSICAL/AESTHETIC PARAMETERS

Parameter	Arithmetic Mean, Blend Tank	Source Contribution (Percent)	
		Blue Plains WWTP	Potomac Estuary
Temperature	18.6°C	NC <sup>1</sup>	NC
pH	7.0	NC	NC
Dissolved Oxygen	8.4 mg/L	48	52
Turbidity (grab samples)	14.05 NTU	10	90
Total Suspended Solids	15.73 mg/L	26	74
Apparent Color	37.3 color units	44	56
MBAS	0.068 mg/L	63	37

1. NC = Not Calculated.

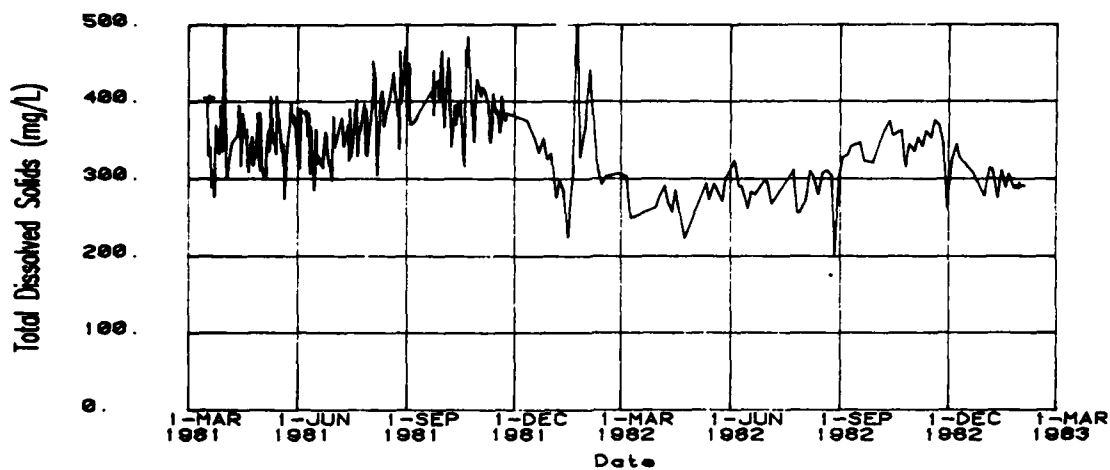
#### MAJOR CATIONS, ANIONS AND NUTRIENTS

The water quality parameters of interest in this group include some of those modeled with the DEM as discussed in Section 1 of this chapter. For these water quality parameters, the Revised Maximum Predicted Concentration (RMPC), discussed in Section 1, is indicated on the time series plots.

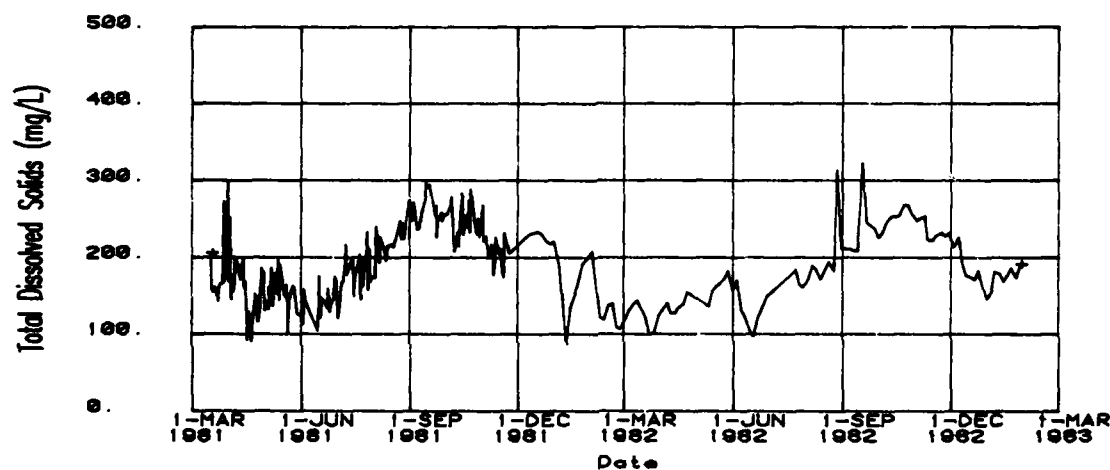
Total dissolved solids (TDS) in the EEWTP source waters and blended influent throughout the two years of EEWTP operation are plotted in Figures 6.3-6(a), (b), and (c). In addition, the RMPC of 310 mg/L is represented by a horizontal line on Figure 6.3-6(c). The RMPC represents the predicted peak one-day concentration reached during the six month period of water quality modeling and is used as the basis of comparison to the observed water quality.

As discussed in Section 2, the selected blend ratio was not expected to provide levels of water quality parameters in the blended influent which would match the predicted levels for all parameters modeled. The selection was based on a comparison of arithmetic mean or 90 percentile concentrations in the source waters to the maximum projected concentration in the estuary. It was not possible to account for variability in the source water concentrations and predicted concentrations. Thus, the time series plots for each modeled water quality parameter illustrate the degree to which the observed levels matched the predicted levels, as well as to illustrate the variability in concentrations with time. Figure 6.3-6(c) shows that TDS concentrations exceeded the RMPC during the first year of operation, but peak levels did not adversely affect the performance of EEWTP unit processes.

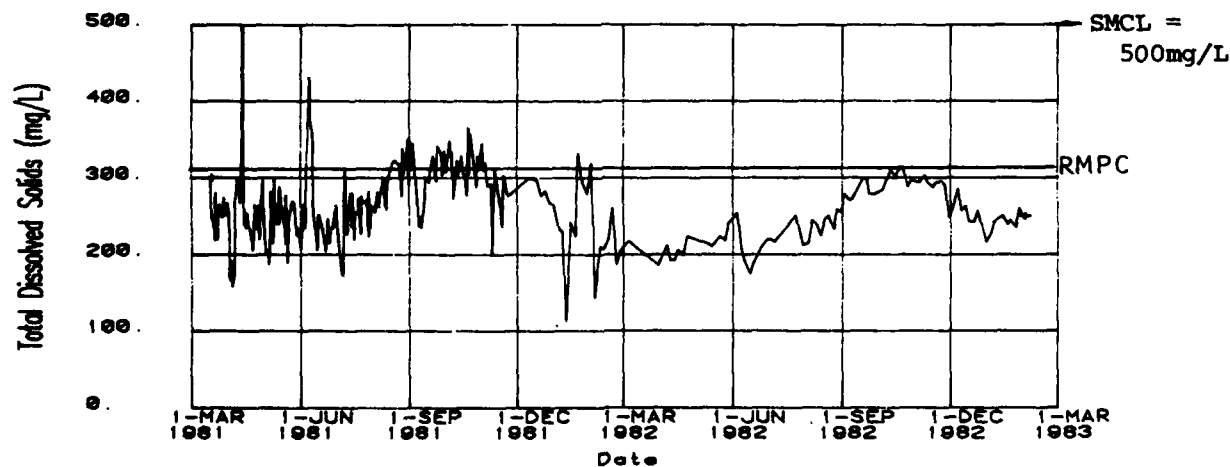
The SMCL for TDS of 500 mg/L is indicated on Figure 6.3-6(c). The concentration of TDS exceeded the SMCL only once during the period of EEWTP operation, and generally varied between 200 and 300 mg/L with seasonal



(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). EEWTP Blended Influent

**TOTAL DISSOLVED SOLIDS (TDS)  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-6**



EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983

variations. Higher levels of TDS were observed during the late summer, corresponding to the historical period of droughts.

Time series plots of sodium in the EEWTP source waters and blended influent are shown in Figures 6.3-7(a), (b), and (c). The RMPC for sodium is 32 mg/L. The concentrations of sodium in the EEWTP blended influent frequently exceeded the RMPC. The very high sodium peaks observed in the nitrified effluent source and, in turn, in the blended influent during winter months (January-March) may be due to salting of roads.

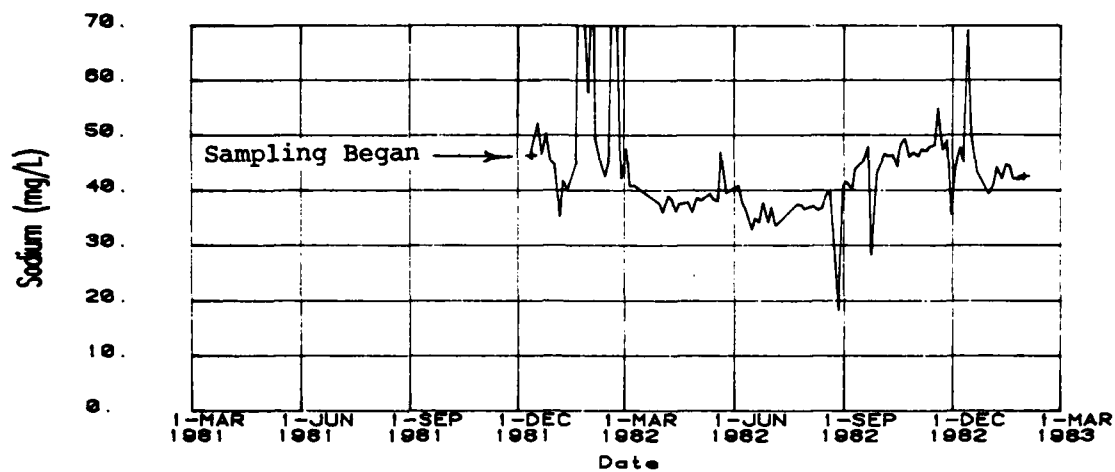
Time series plots of alkalinity are shown in Figures 6.3-8(a), (b), and (c). Although not regulated under the NIPDWR, alkalinity is of interest because of its effects on coagulation. As the RMPC could not be calculated for this parameter, for reasons discussed in Section 1, the horizontal line represents the background concentration in the Potomac River as a worst case comparison. The variation of alkalinity in the blended influent shows seasonal trends, with alkalinity increasing during winter months.

Time series plots of bromide are shown in Figures 6.3-9(a), (b), and (c). Bromide is of interest because of its role in the formation of brominated organic compounds. Bromide may be oxidized to hypobromous acid (HOBr) and subsequently react with organic matter, as measured by TOC, to form brominated organics. During the two year operation of the EEWTP, bromide concentrations were sometimes measured below the method detection limit of 0.003 mg/L in the EEWTP blended influent. In these and subsequent figures in this chapter, values below the detection limit are plotted as zero.

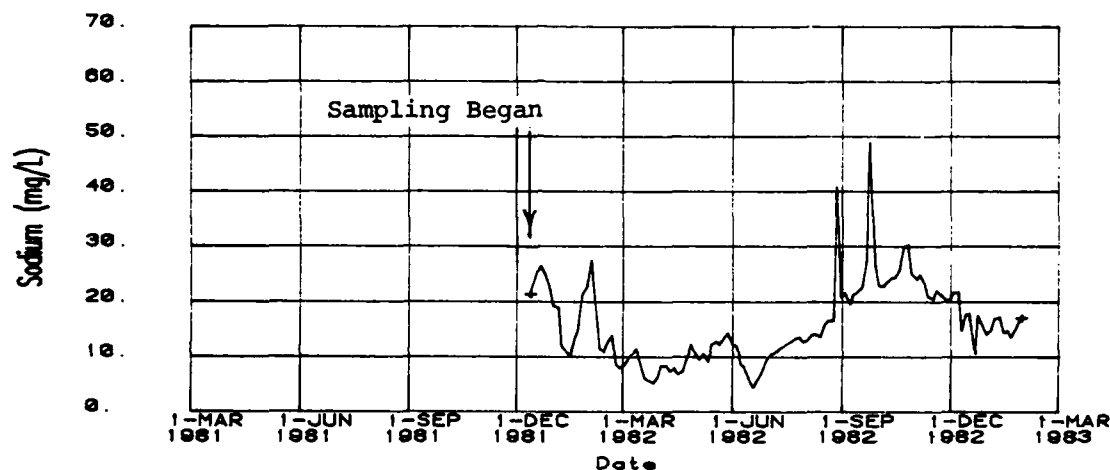
Time series plots of chloride concentration in the EEWTP source waters and blended influent are shown in Figures 6.3-10(a), (b), and (c). Chloride is of interest because the degree of salinity of a given water is classified based on chloride concentration and it is a conservative parameter useful in comparing the quality of the EEWTP blended influent to the modeled drought condition. The chloride concentrations in the blended influent often exceeded the RMPC of 50.3 mg/L, but never exceeded the SMCL of 250 mg/L. As with the several peaks of sodium during winter months discussed above, the peaks of chloride concentration in the nitrified effluent source and blended influent may be due to salting of roads. However, during the entire period of operation, the range of chloride concentrations in the EEWTP blended influent fall within the classification of a "tidal-fresh estuary", i.e., chloride concentration less than 500 mg/L.

Time series plots of total cyanide are shown in Figures 6.3-11(a), (b), and (c). Cyanide is included among the parameters of interest because of its adverse health effects, which are discussed in Chapter 9. Observed levels of total cyanide in the blended influent were fairly constant throughout the period of EEWTP operation, and were always less than 0.04 mg/L.

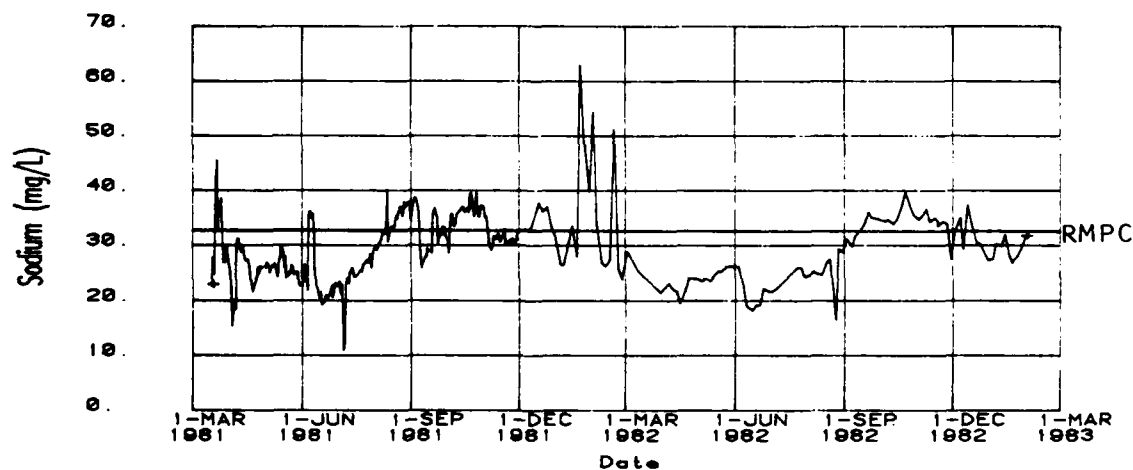
Concentration variations of nitrate and nitrite species are shown in time series plots in Figures 6.3-12(a), (b), and (c). The RMPC of 8.9 mg/L, and MCL of 10 mg/L are shown on Figure 6.3-12(c). There were three periods during



(a). Blue Plains Nitrified Effluent

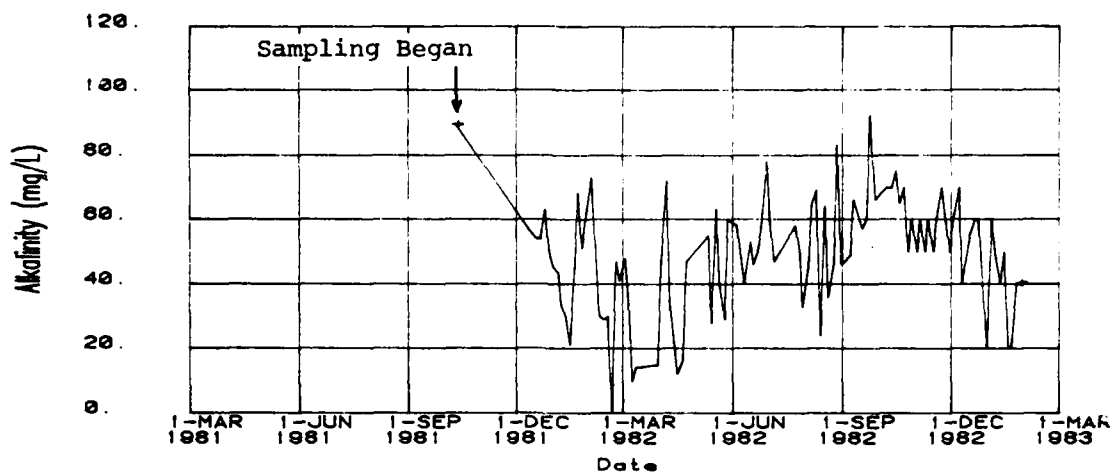


(b). Potomac Estuary Water

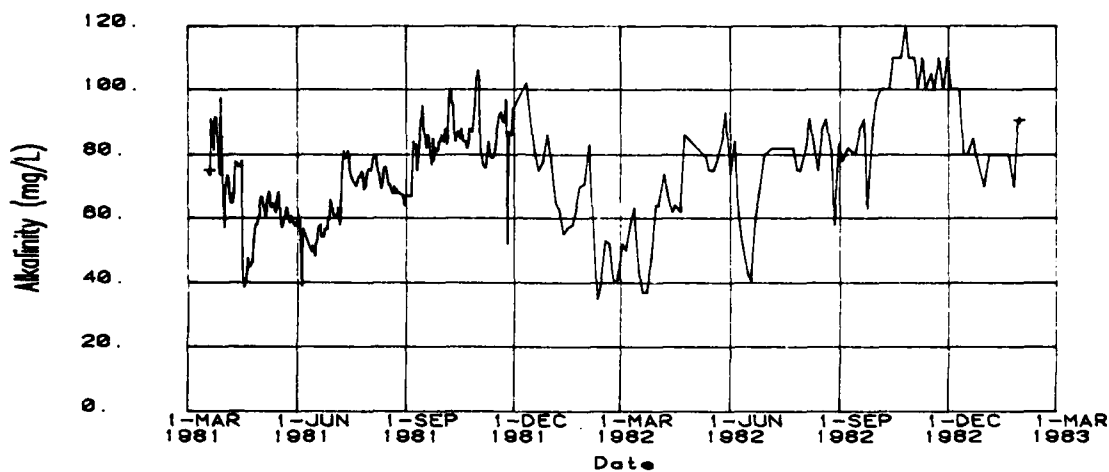


(c). EEWTP Blended Influent

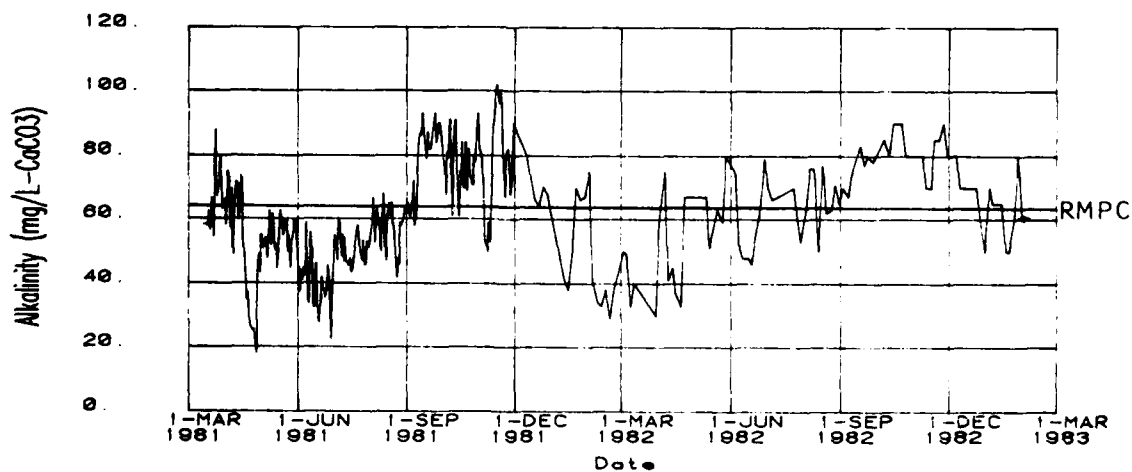
**SODIUM**  
**IN EEWTP SOURCE WATERS AND BLENDED INFLUENT**  
**FIGURE 6. 3-7**



(a). Blue Plains Nitrified Effluent

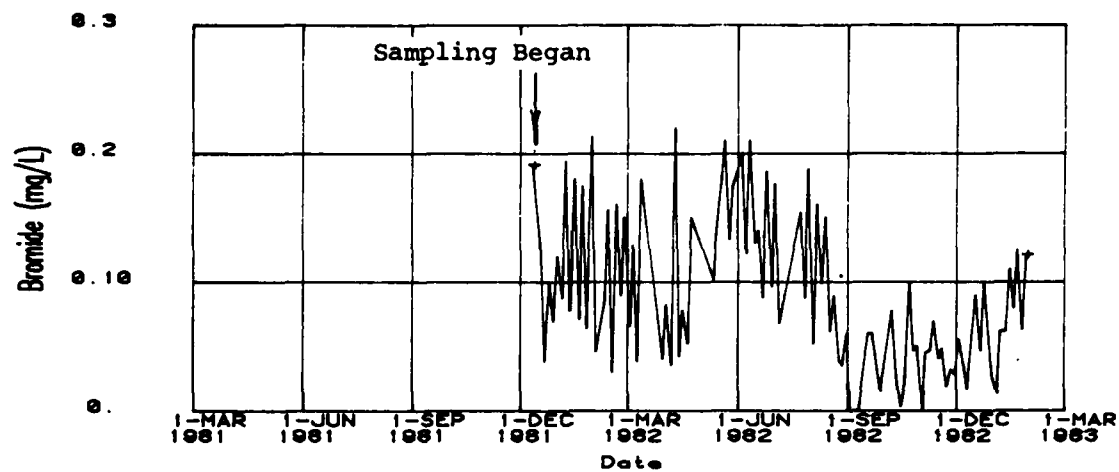


(b). Potomac Estuary Water

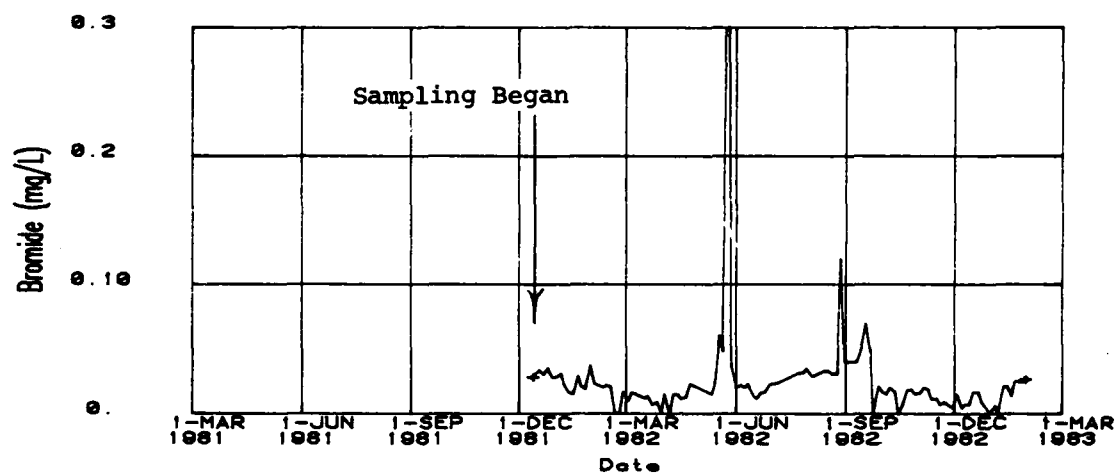


(c). EEWTP Blended Influent

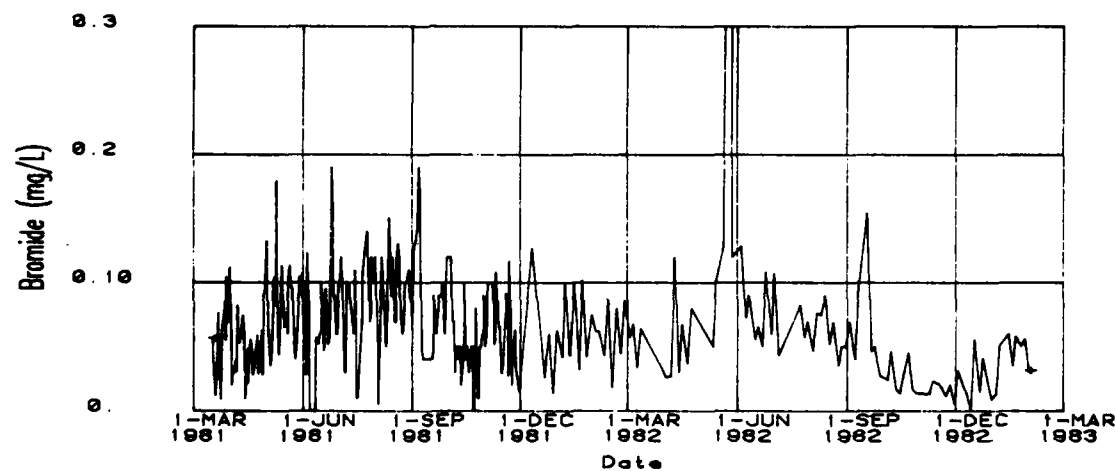
**ALKALINITY**  
**IN EEWTP SOURCE WATERS AND BLENDED INFLUENT**  
**FIGURE 6. 3-8**



(a). Blue Plains Nitrified Effluent

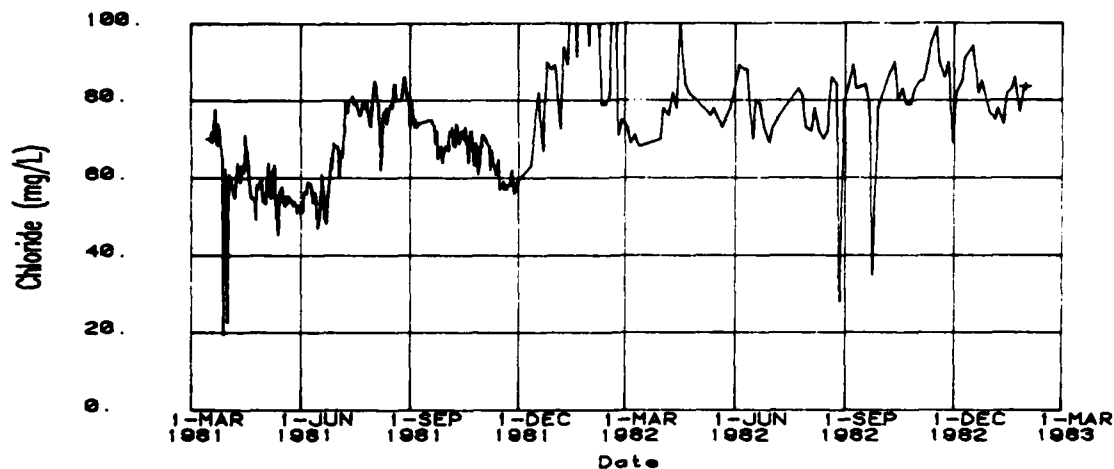


(b). Potomac Estuary Water

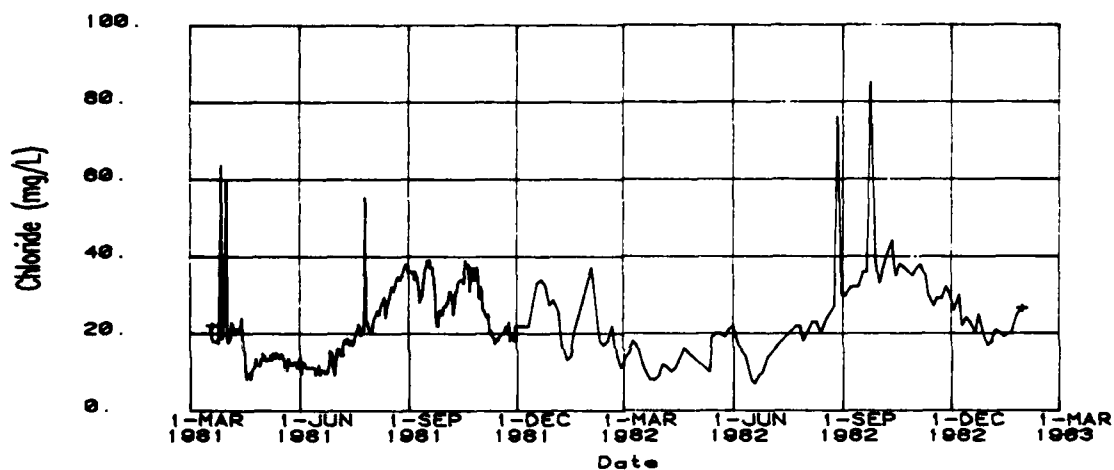


(c). EEWTP Blended Influent

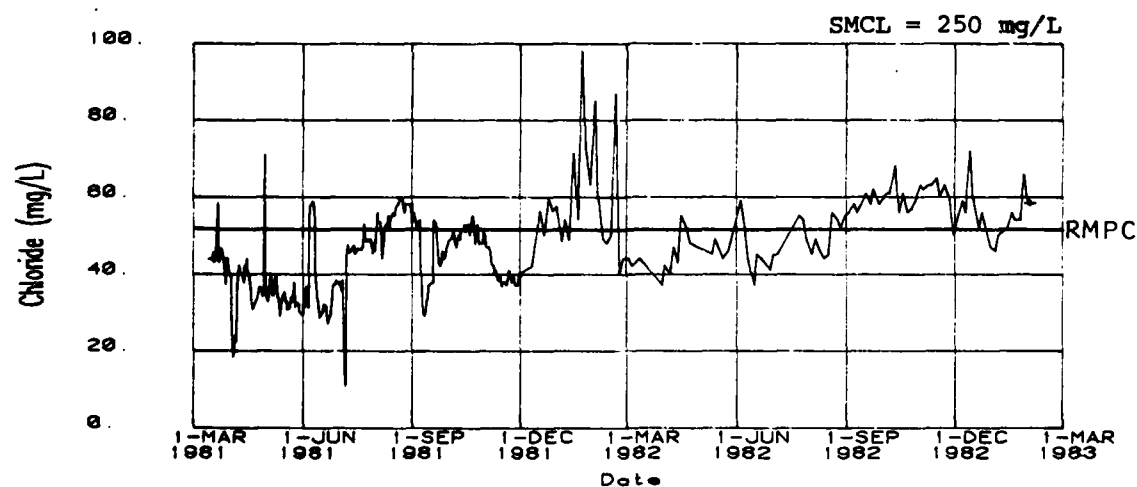
**BROMIDE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6.3-9**



(a). Blue Plains Nitrified Effluent

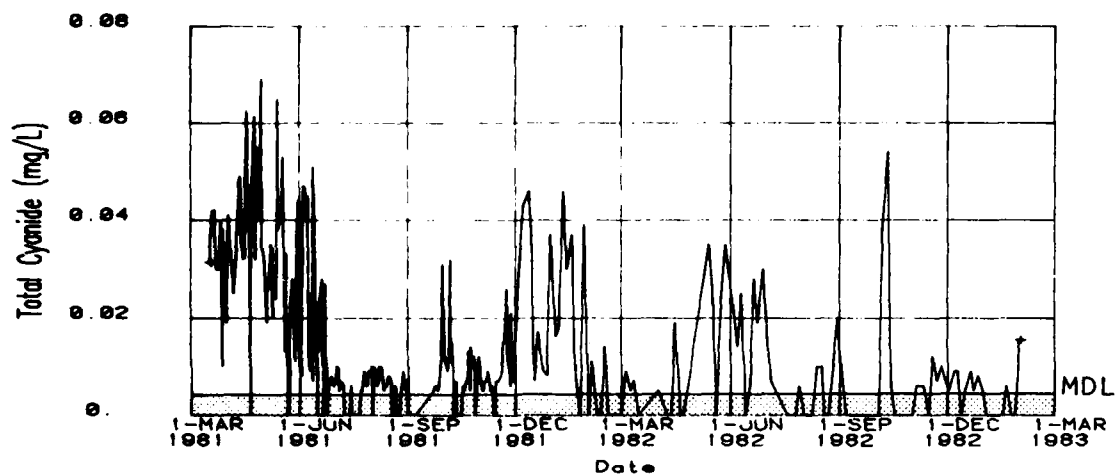


(b). Potomac Estuary Water

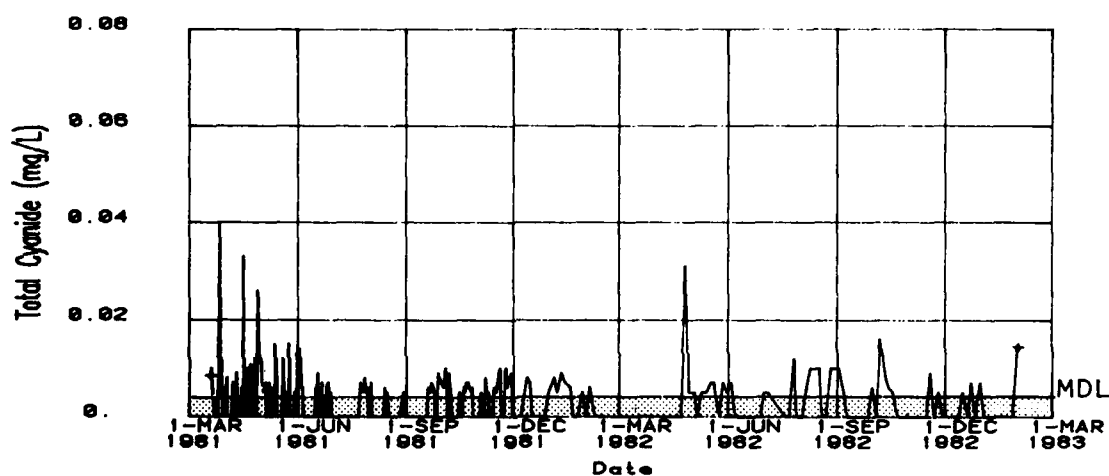


(c). EEWTP Blended Influent

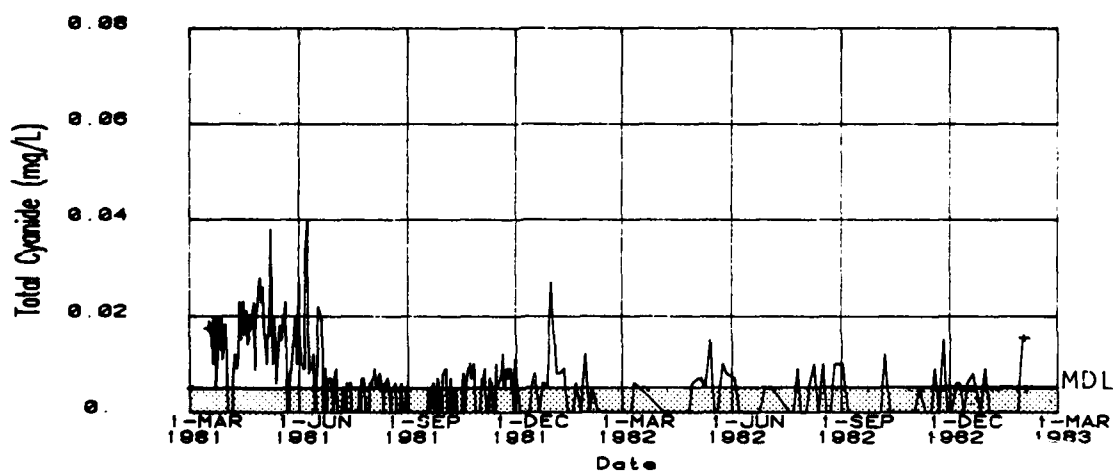
**CHLORIDE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-10**



(a). Blue Plains Nitrified Effluent

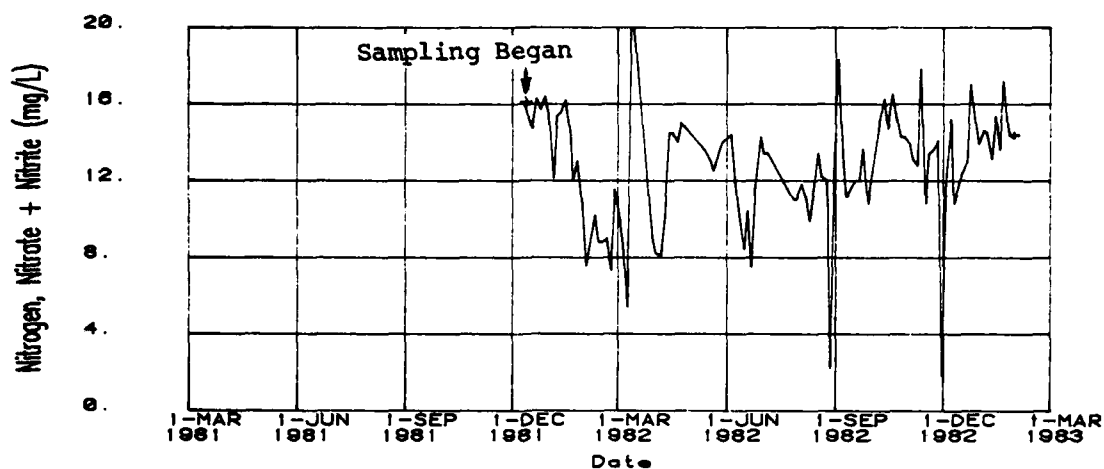


(b). Potomac Estuary Water

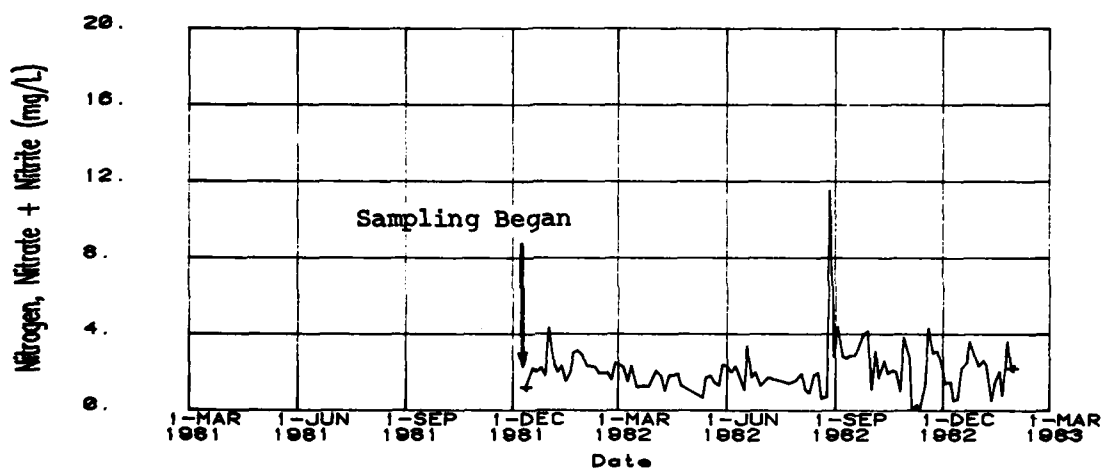


(c). EEWTP Blended Influent

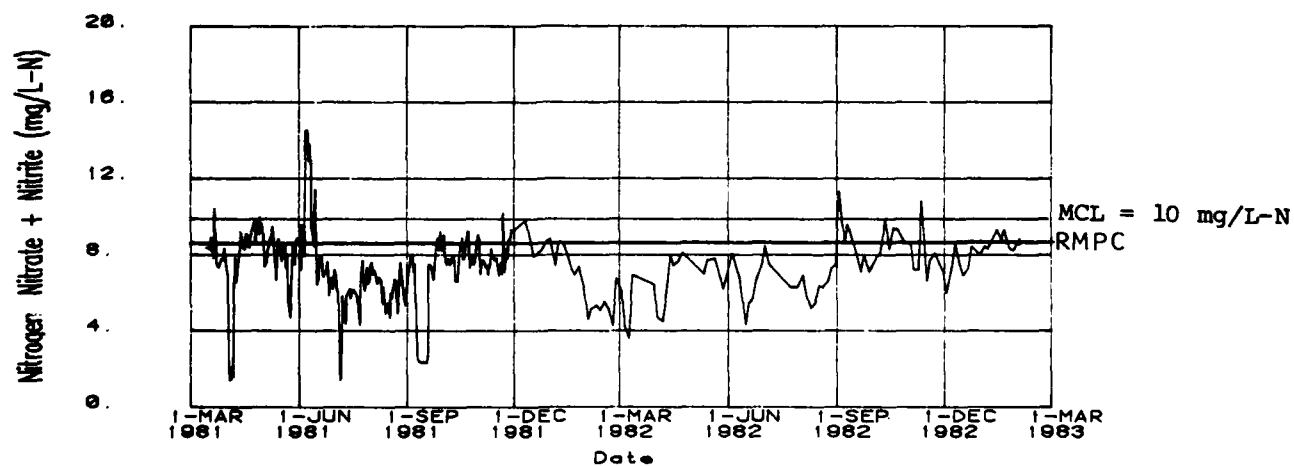
**TOTAL CYANIDE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-11**



(a) Blue Plains Nitrified Effluent



(b) Potomac Estuary Water



(c) EEWTP Blended Influent

**NITRATE + NITRITE NITROGEN  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-12**

EEWTP Influent Water Quality Monitoring  
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EEWTP operation when the blended influent concentration exceeded both the RMPC and MDL. No clear seasonal trends were observed.

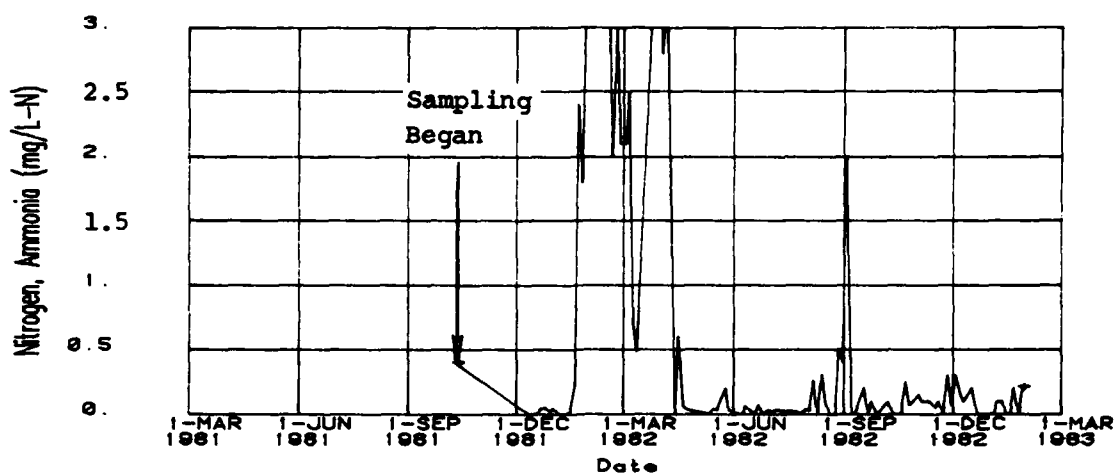
The ammonia species of inorganic nitrogen is shown in time series plots in Figures 6.3-13(a), (b), and (c). The detection limit for ammonia was 0.02 mg/L. Concentrations measured in the EEWTP blended influent show three periods where the ammonia concentrations exceeded the RMPC of 0.4 mg/L. The concentration of ammonia in the blended influent was highly variable, with concentrations in the blended influent greatly influenced by the efficiency of the nitrification facility at Blue Plains WWTP. These nitrification upsets, which resulted in high ammonia levels, occurred during the winter months due to low temperatures. The high ammonia levels in the EEWTP blended influent reduced the efficiency of chlorine disinfection through the formation of chloramines, an issue discussed in Chapter 7 and 8.

One of the scenarios modeled with the DEM, discussed in Section 1, considered the effect of nitrification breakdown on ammonia levels in the estuary assuming no decay. The results, which were thus very conservative, showed that ammonia levels between 1 and 7 mg/L could be expected under future drought conditions depending upon treatment plant intake and length of nitrification breakdown. This scenario would be more likely in the winter months, as during the summer months, corresponding to the historic period of droughts, nitrification in both the wastewater treatment plants and within the estuary would keep ammonia levels lower.

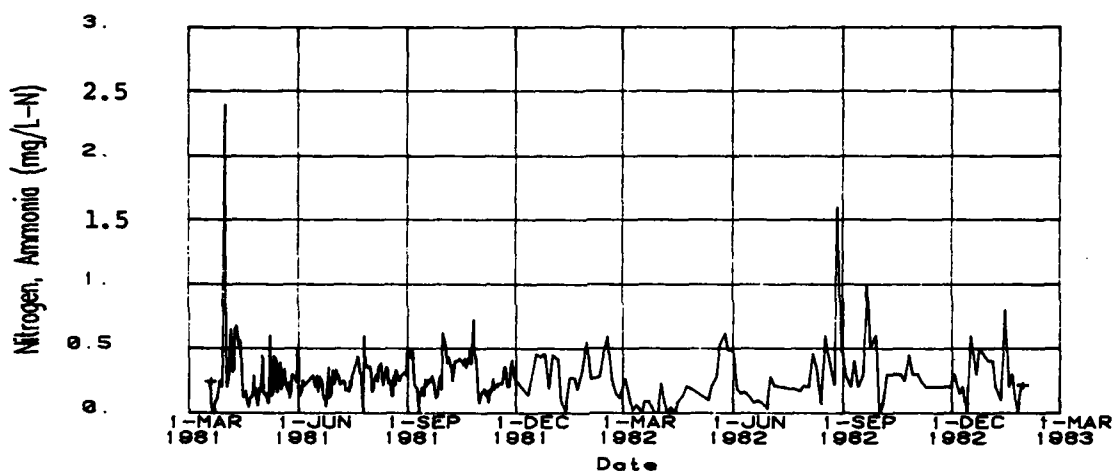
Time series plots of sulfate in the EEWTP source waters and blended influent are shown in Figures 6.3-14(a), (b), and (c). Concentrations of sulfate often exceed the RMPC of 62.2 mg/L through January 1982, but never exceeded the SMCL of 250 mg/L. Figure 6.3-14(b) shows a seasonal variation in sulfate concentrations in the estuary source, which is reflected in the variations in the blended influent. A comparison with the streamflows plotted in Figure 6.3-1 shows that sulfate concentrations decrease with increasing streamflow.

The source contributions for the major cations, anions, and nutrients are listed in Table 6.3-2. As expected, except for alkalinity, higher proportions of these parameters were provided by the nitrified effluent due to concentration increases by water treatment, municipal use, and wastewater collection and treatment. The RMPCs for modeled water quality parameters were exceeded often in some cases, but the simulation of projected estuary water quality was generally accurate. The RMPC matches the 90 percentile, or at least the arithmetic mean, concentration in the blended influent. With the exception of ammonia, although concentration variations for this group of parameters sometimes exceeded the RMPC, they were not of sufficient magnitude to affect the performance of EEWTP unit processes in removing parameters of concern.

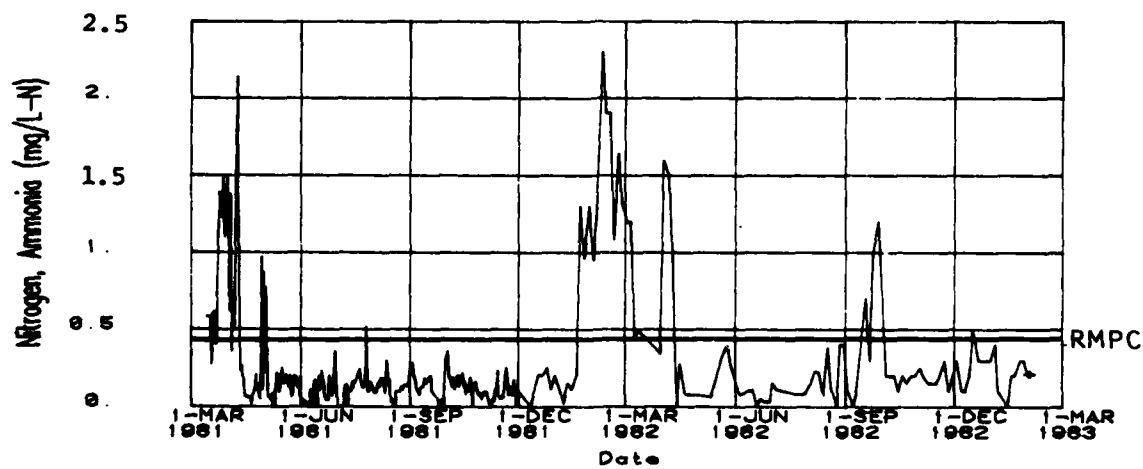




(a). Blue Plains Nitrified Effluent

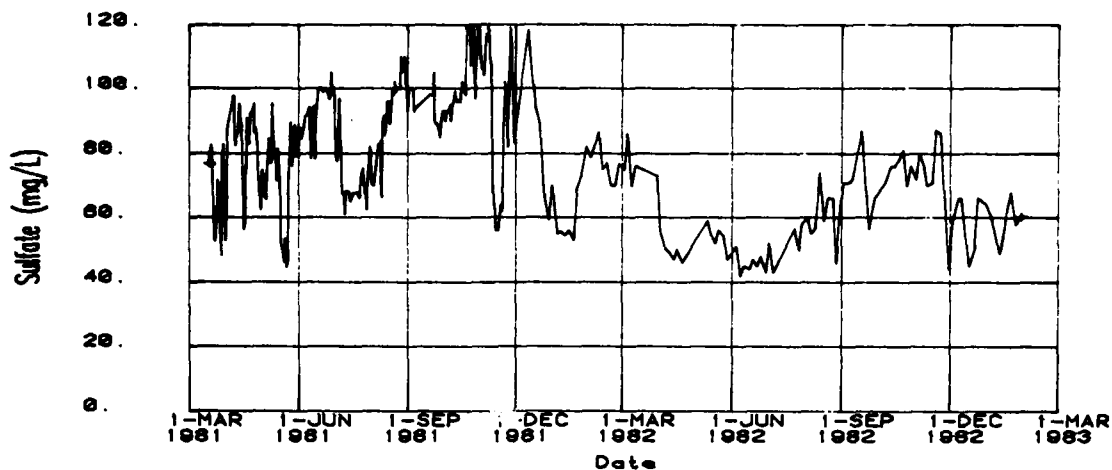


(b). Potomac Estuary Water

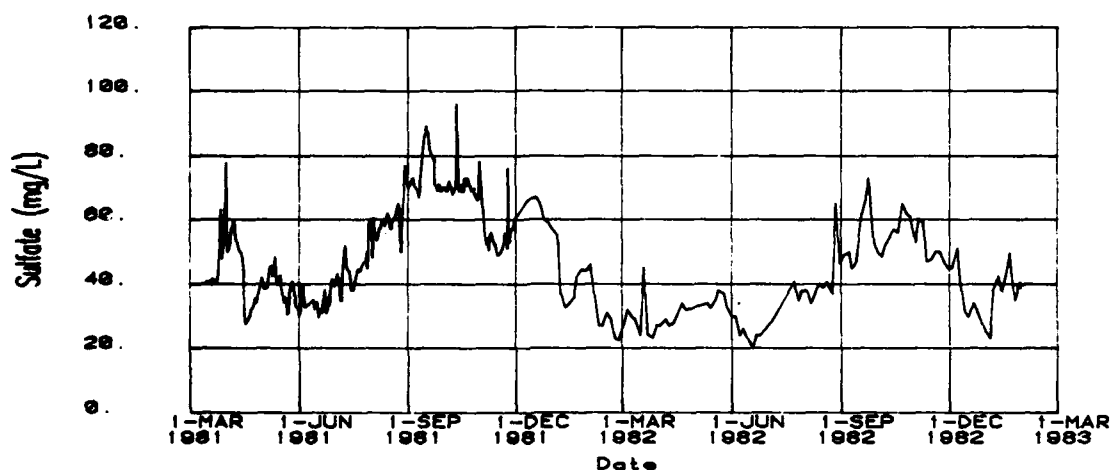


(c). EEWTP Blended Influent

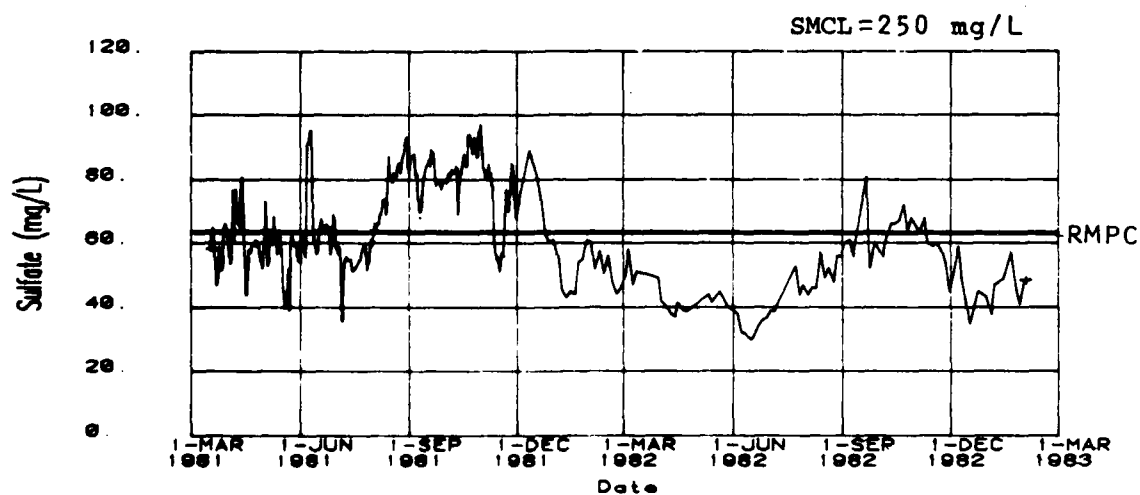
**AMMONIA NITROGEN  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-13**



(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). ELWTP Blended Influent

**SULFATE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-14**

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TABLE 6.3-2  
SOURCE CONTRIBUTIONS  
MAJOR CATIONS, ANIONS, AND NUTRIENTS

Parameter	Arithmetic Mean, Blend Tank	Source Contribution (Percent)	
		Blue Plains WWTP	Potomac Estuary
Total Dissolved Solids			
(by evaporation)	268.3 mg/L	66	34
(by addition)	246.5 mg/L	63	37
Electroconductivity	451.1 $\mu$ mho/cm	65	35
Calcium	46.82 mg/L	60	40
Hardness	150.8 mg/L-CaCO <sub>3</sub>	58	42
Magnesium	8.2 mg/L	51	49
Potassium	6.0 mg/L	74	26
Sodium	29.4 mg/L	73	27
Alkalinity	62.19 mg/L-CaCO <sub>3</sub>	40	60
Bromide	0.066 mg/L	81	19
Chloride	45.8 mg/L	76	24
Cyanide, Total	0.008 mg/L	77	23
Flouride	0.51 mg/L	82	18
Iodide	0.005 mg/L	62	38
Nitrogen, Nitrite+			
Nitrate	7.31 mg/L-N	86	14
Nitrogen, Ammonia	0.26 mg/L-N	68	32
Nitrogen, Total			
Kjeldahl	1.0 mg/L-N	64	36
Ortho Phosphate	0.38 mg/L-P	80	20
Silica	6.8 mg/L	65	35
Sulfate	63.5 mg/L	62	38

**EEWTP Influent Water Quality Monitoring  
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**TRACE METALS**

The remainder of water quality parameters modeled using the DEM are included in this group of parameters. Where applicable, the RMPC is shown on the time series plot for the EEWTP blended influent.

Time series plots of lead concentration are shown in Figures 6.3-15(a), (b) and (c). Measured concentrations in the EEWTP blended influent often exceeded the RMPC of 0.002 mg/L during the two years of EEWTP operation. However, concentrations exceeded the MCL of 0.05 mg/L only once in the blended influent. The peaks in lead concentrations occurred during the late summer and autumn months, corresponding to historic periods of low streamflow.

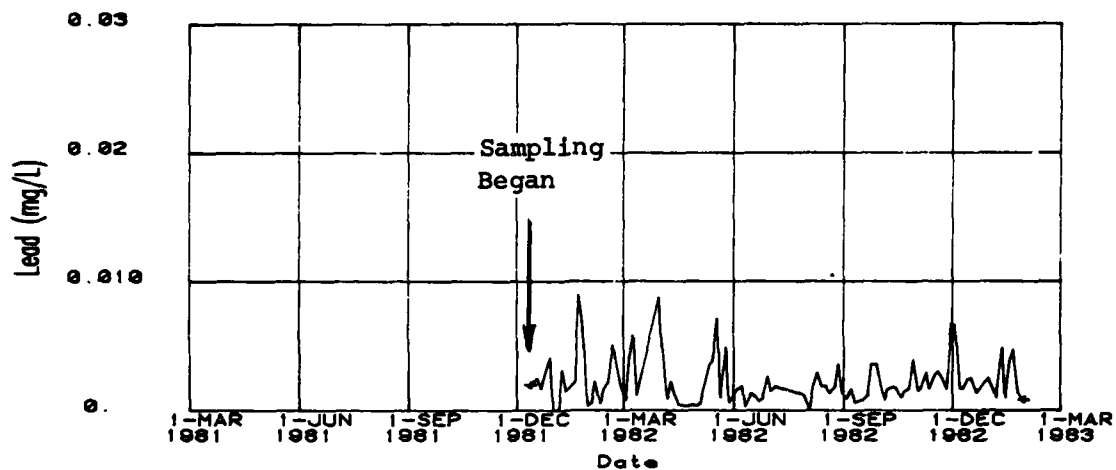
Time series plots of manganese concentration are shown in Figures 6.3-16(a), (b), and (c). Concentrations in the EEWTP blended influent often exceeded the RMPC of 0.19 mg/L and, in most samples taken throughout the two years of EEWTP operation, were greater than the SMCL of 0.05 mg/L. Similar to lead, higher concentrations of manganese occurred during the summer and autumn months.

Time series plots of mercury concentration are shown in Figure 6.3-17(a), (b), and (c). Mercury concentrations measured in the EEWTP blended influent exceeded the RMPC of 0.0002 mg/L several times throughout the period of plant operation. However, the MCL for mercury, which is an order of magnitude greater than the RMPC, 0.002 mg/L, was exceeded only three times in the two years of operation. Variations in mercury concentration showed no clear seasonal trends. The grey shaded area at the bottom of each figure represents concentrations less than the method detection limit of 0.00027 mg/L.

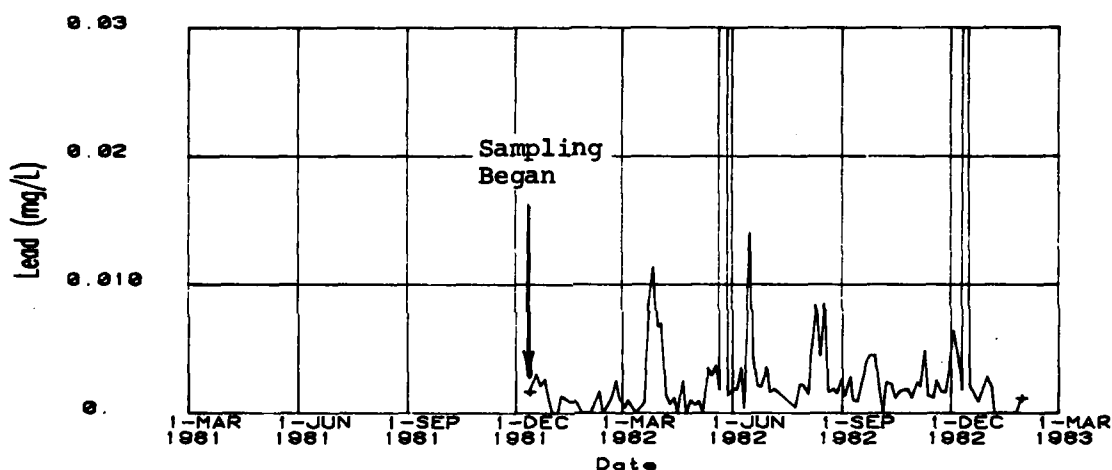
Time series plots of nickel concentration are shown in Figures 6.3-18(a), (b), and (c). Observed concentrations in the blended influent greater than the RMPC of 0.01 mg/L occurred more often during the summer and autumn months. Again, the gray shaded area at the bottom of the figures represents concentrations less than the method detection limit of 0.001 mg/L.

Time series plots of selenium concentration are shown in Figures 6.3-19(a), (b), and (c). Observed selenium concentrations in the blended influent were higher in samples before November 1981, and showed no clear seasonal trends. Between September and November 1981, a number of peak selenium concentrations were greater than 0.005 mg/L and also exceeded the MCL of 0.01 mg/L.

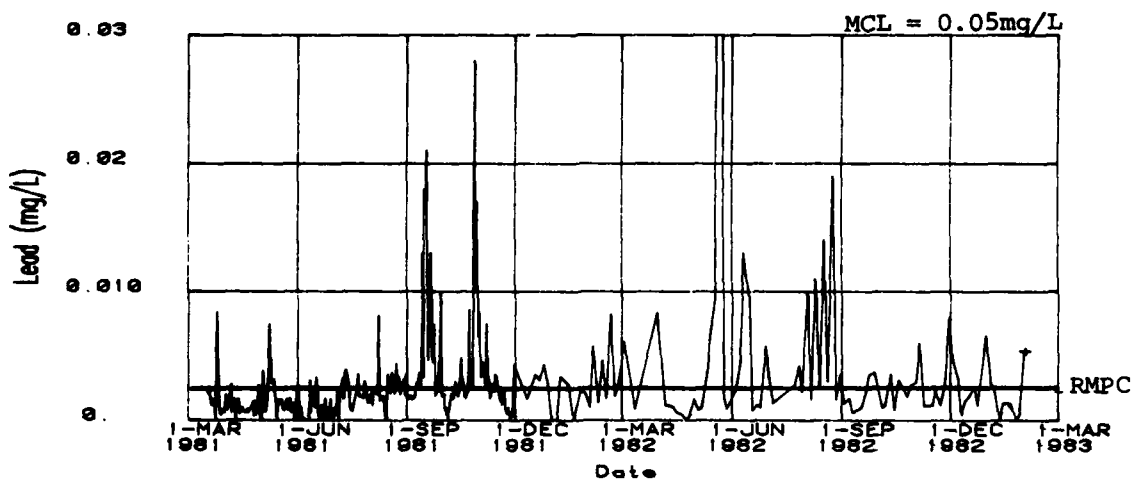
Table 6.3-3 lists the source contributions for trace metals in the EEWTP blended influent. Unlike the major anions, cations, and nutrients, the trace metals were generally not contributed by a single source water. For the modeled parameters within the trace metal group, the RMPC matched the 90 percentile, or at least the arithmetic mean, concentration in the blended influent. Thus, the simulation of projected estuary water quality was generally



(a). Blue Plains Nitrified Effluent

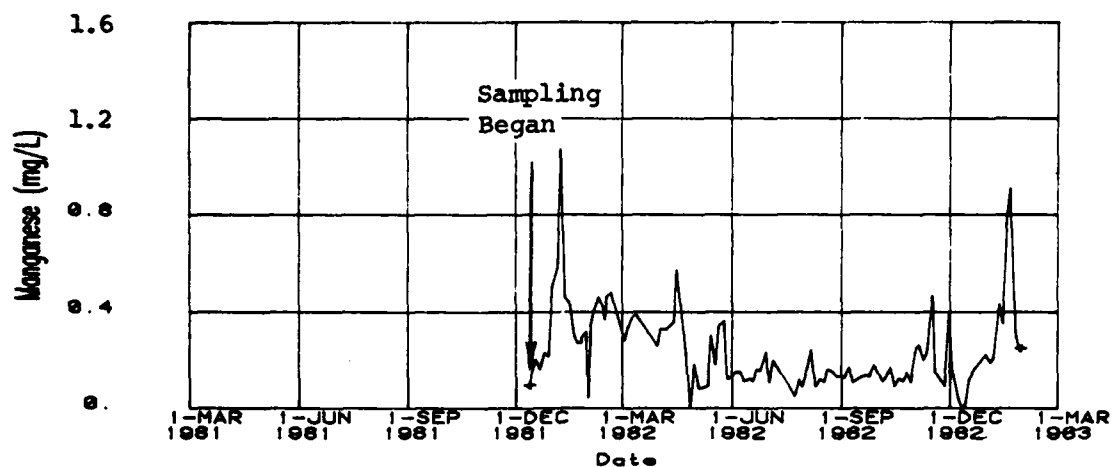


(b). Potomac Estuary Water

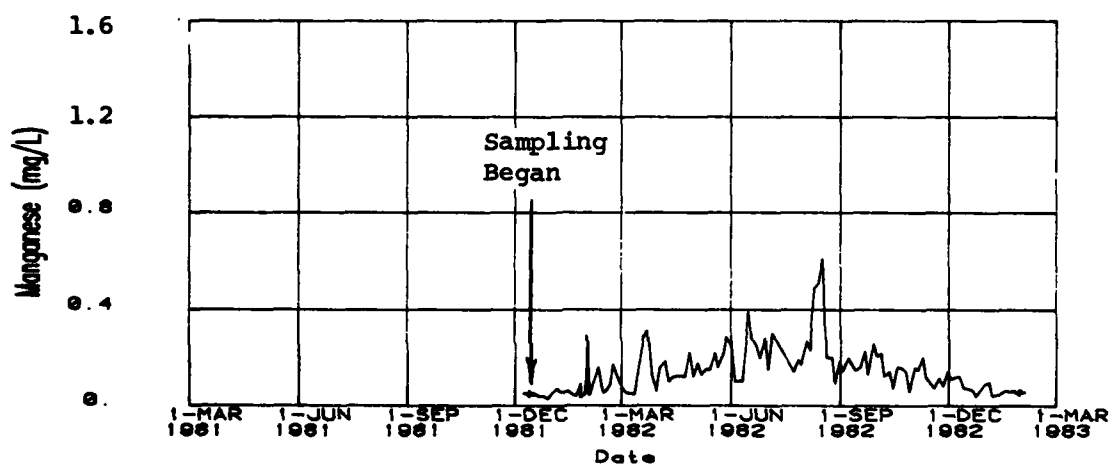


(c). EEWTP Blended Influent

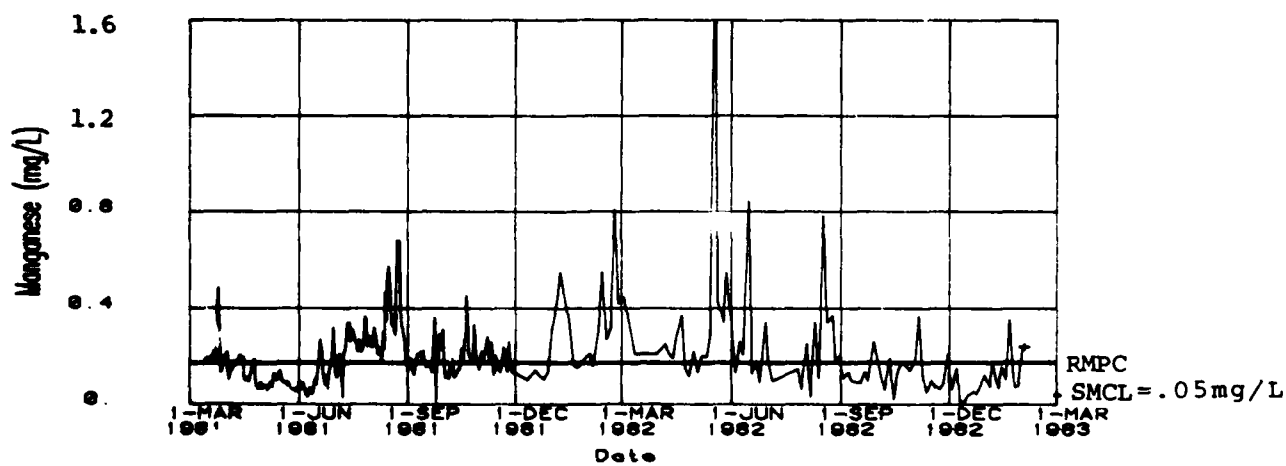
**LEAD  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-15**



(a). Blue Plains Nitrified Effluent

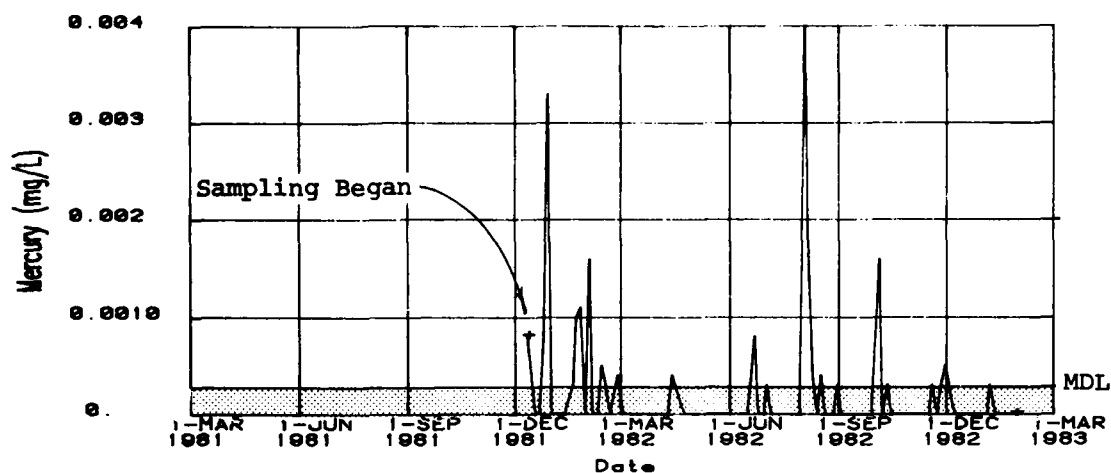


(b). Potomac Estuary Water

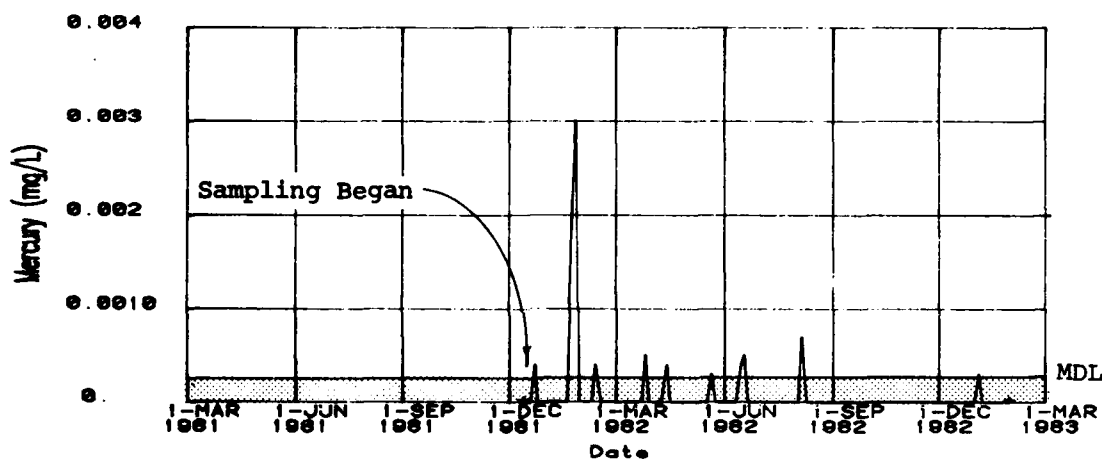


(c). EEWTP Blended Influent

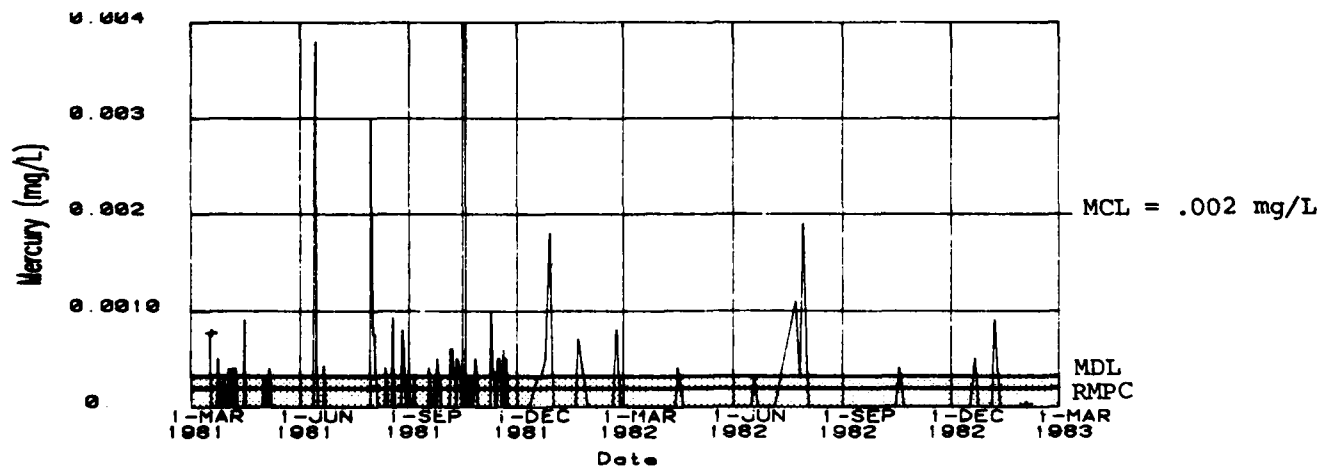
**MANGANESE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-16**



(a). Blue Plains Nitrified Effluent

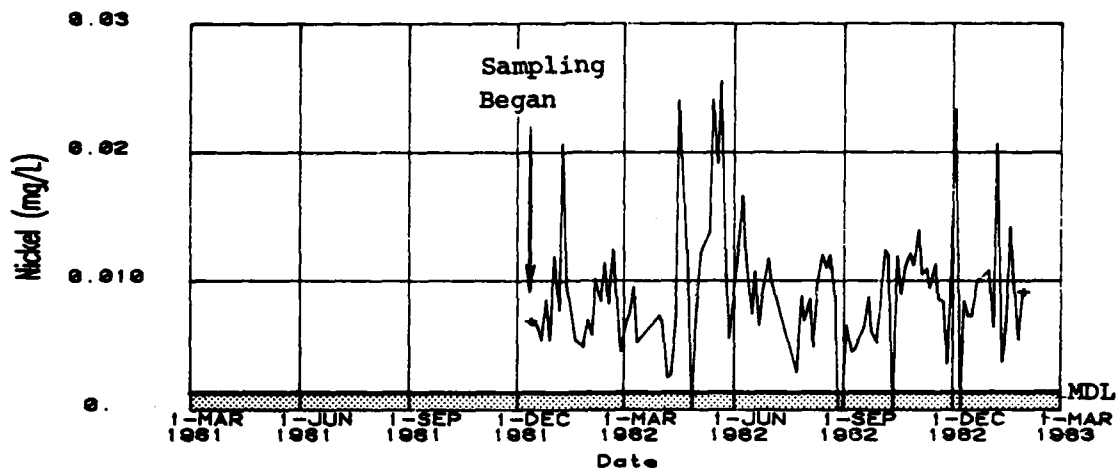


(b). Potomac Estuary Water

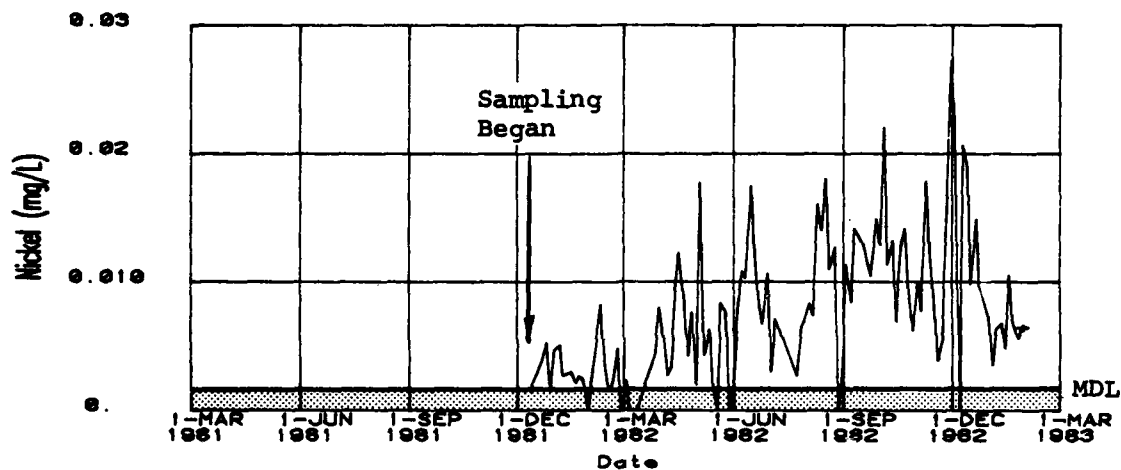


(c). EEWTP Blended Influent

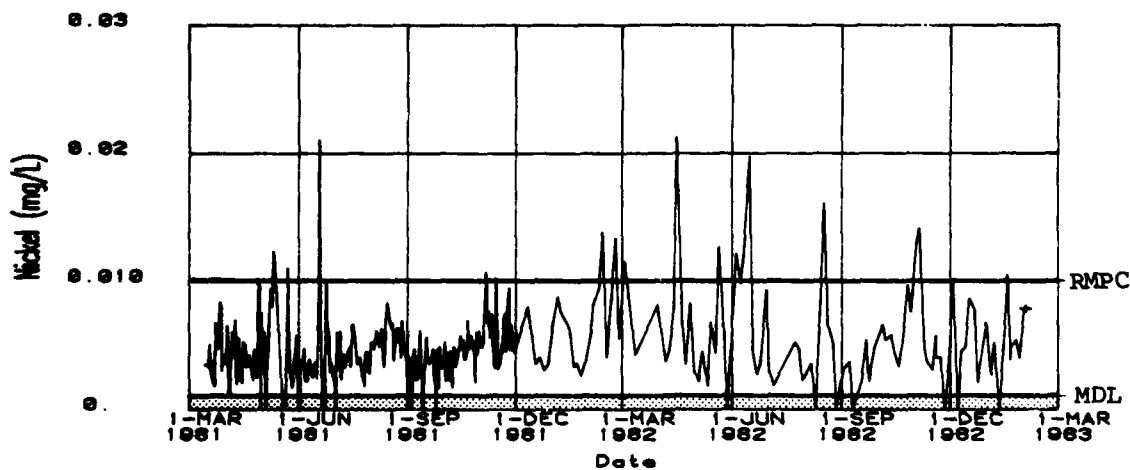
**MERCURY**  
**IN EEWTP SOURCE WATERS AND BLENDED INFLUENT**  
**FIGURE 6. 3-17**



(a). Blue Plains Nitrified Effluent



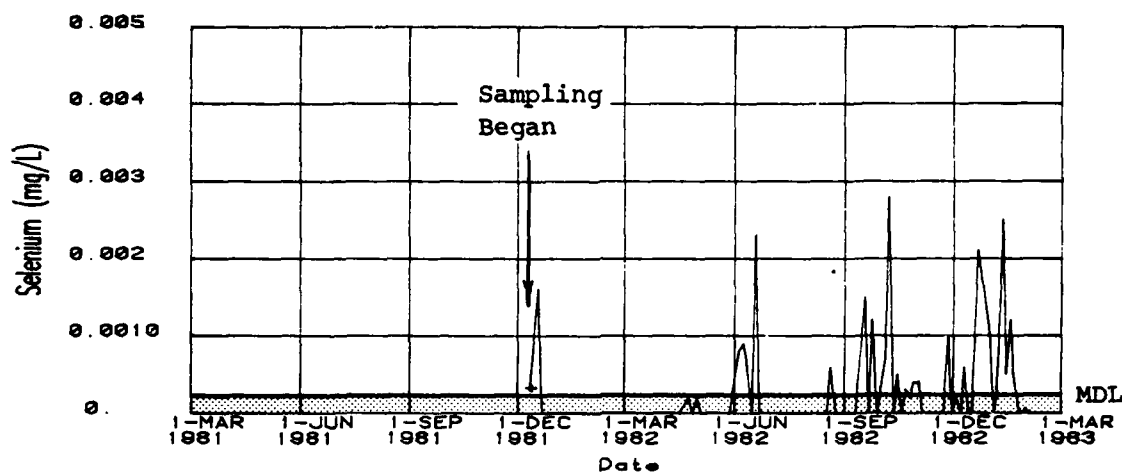
(b). Potomac Estuary Water



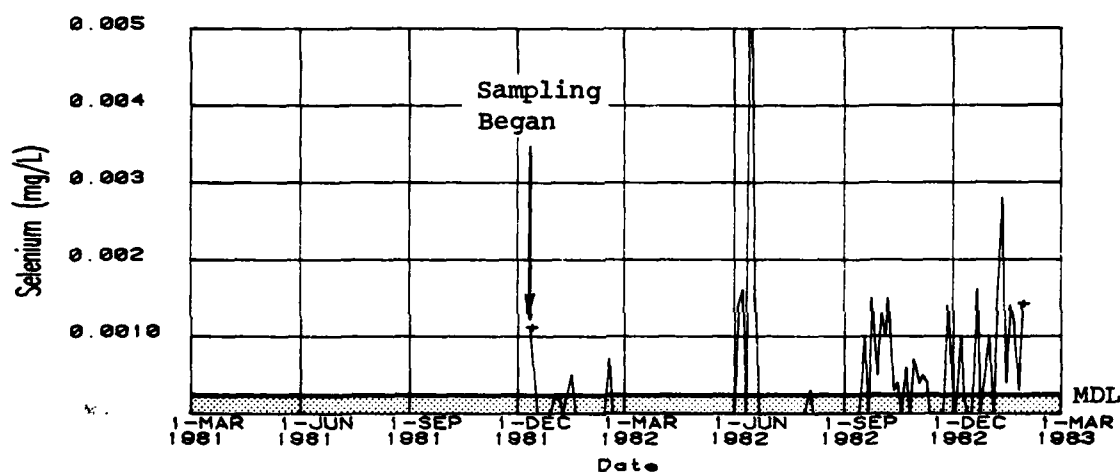
(c). EEWTP Blended Influent

**NICKEL  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-18**

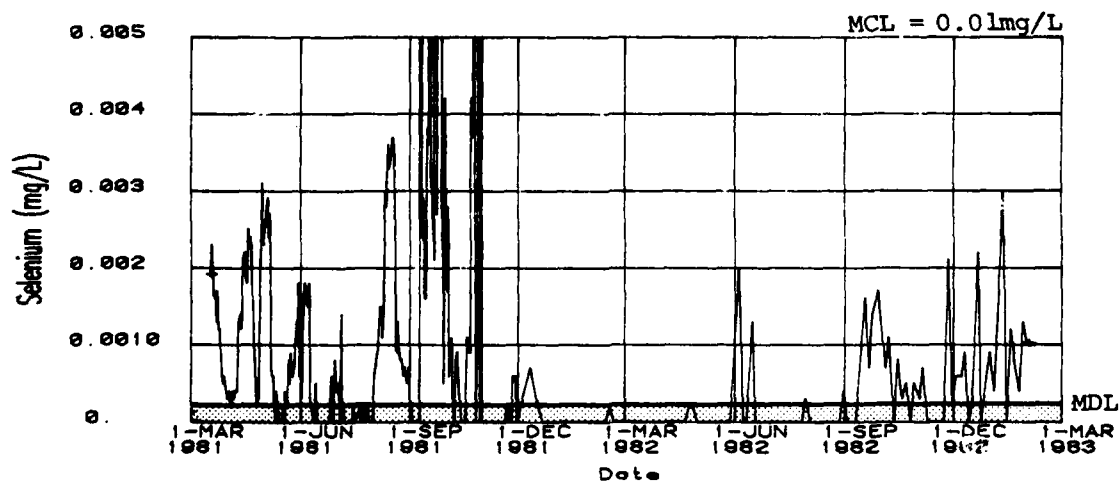




(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). EEWTP Blended Influent

**SELENIUM**  
**IN EEWTP SOURCE WATERS AND BLENDED INFLUENT**  
**FIGURE 6. 3-19**

EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983

TABLE 6.3-3  
SOURCE CONTRIBUTIONS  
TRACE METALS

Parameter	Arithmetic Mean Blend Tank (mg/L)	Source Contribution (Percent)	
		Blue Plains WWTP	Potomac Estuary
Aluminum	0.469	18	82
Antimony	0.0006	50	50
Arsenic	0.0012	35	65
Barium	0.033	32	68
Beryllium	ND <sup>2</sup>	NA <sup>3</sup>	NA <sup>3</sup>
Boron	0.0513	77	23
Cadmium <sup>1</sup>	0.0002	30	70
Chromium <sup>1</sup>	0.0067	65	35
Cobalt <sup>1</sup>	0.0052	73	27
Copper <sup>1</sup>	0.0089	65	35
Iron	1.370	56	44
Lead	0.0030	12	88
Lithium <sup>1</sup>	0.0059	62	38
Manganese	0.1971	63	37
Mercury	0.00048	62	38
Molybdenum	0.001	44	56
Nickel	0.0049	54	46
Selenium	0.0010	43	57
Silver	0.0006	78	22
Thallium	0.0005	NA <sup>3</sup>	NA <sup>3</sup>
Titanium	0.012	75	25
Vanadium	0.0048	66	34
Zinc	0.0256	63	37

1. Calculated using data as measured by AAS.

2. ND = Not detected in blended influent.

3. NA = Not Applicable, values ND in source waters.

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quite good. In addition, concentration variations in the blended influent for this group of parameters were not of sufficient magnitude to adversely affect the performance of EEWTP unit processes in removing parameters of concern.

#### RADIOLOGICAL PARAMETERS

Radiological parameters were not included in the modeling efforts described in Section 1 of this chapter. Thus, RMPCs were not available for these water quality parameters.

Time series plots of gross beta radiation are shown in Figures 6.3-20(a), (b), and (c). The levels of gross beta radiation in the blended influent showed considerable variation through October 1981 and subsequently leveled off. Reasons for this are unknown.

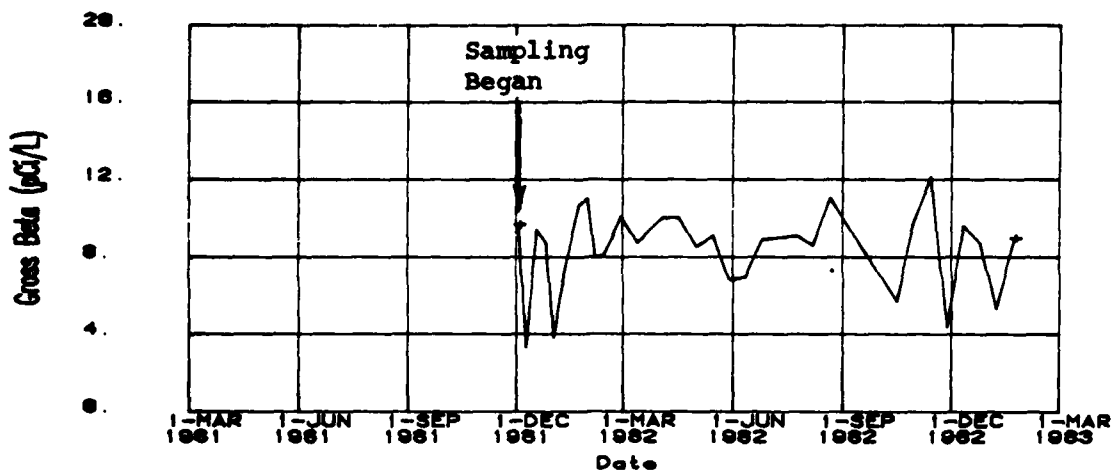
Table 6.3-4 shows the source contributions for radiological parameters in the EEWTP blended influent. Source contributions for Strontium-90 could not be calculated. While levels of gross alpha radiation were approximately the same in the two source waters, the Blue Plains nitrified effluent contributed most of the gross beta radiation. Because gross beta activity reflects the presence of man-made radionuclides, such as radiopharmaceuticals, this result was not unexpected.

#### MICROBIOLOGICAL PARAMETERS

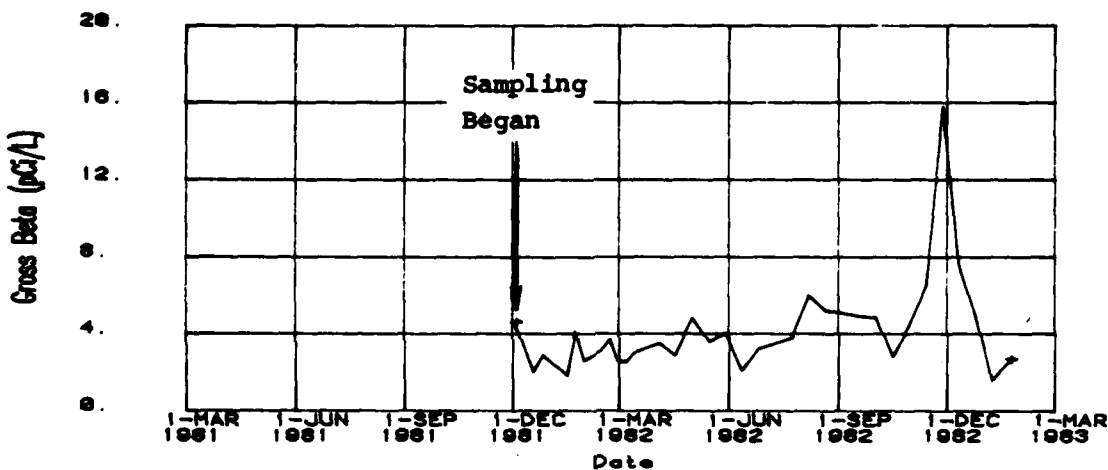
Because microbiological parameters cannot be considered conservative in an estuarine environment, these parameters were not included in the DEM modeling efforts described above. Thus, RMPCs are not available for these parameters.

Time series plots of total coliforms and standard plate count (SPC) in the EEWTP source water and blended influent are shown in Figures 6.3-21(a), (b), and (c), and 6.3-22(a), (b), and (c), respectively. As expected, because of the high levels of coliforms in the nitrified effluent, the blended influent coliform levels exceeded the MCL throughout the two year period of EEWTP operation. Observed concentrations for both total coliforms and SPC in the blended influent were highly variable, ranging over three orders of magnitude for total coliforms and two orders of magnitude for SPC. For total coliforms, concentrations were more variable in the estuary source water. No clear seasonal trends were observed for either parameter in the blended influent.

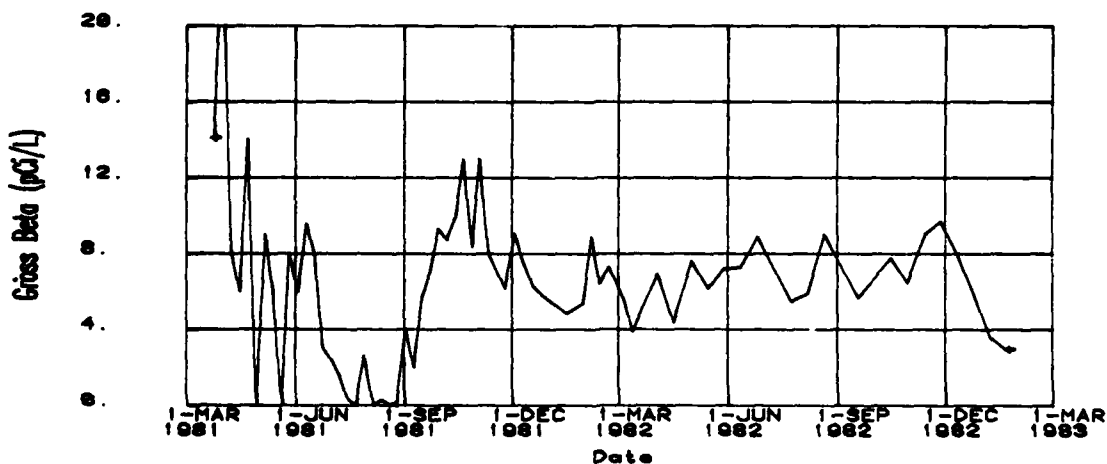
Table 6.3-5 shows the source contributions for microbiological parameters in the EEWTP blended influent. Higher levels of these microbiological parameters were contributed by the nitrified effluent source. A greater seasonal variation in the levels of total coliforms and SPC would be expected in a full-scale estuary water treatment plant, due to microbial dynamics and temperature variations within the estuary, with higher levels occurring in the summer months. However, the observed concentration variations for these parameters were not of sufficient magnitude to adversely affect the performance of EEWTP unit processes in removing parameters of concern.



(a). Blue Plains Nitrified Effluent

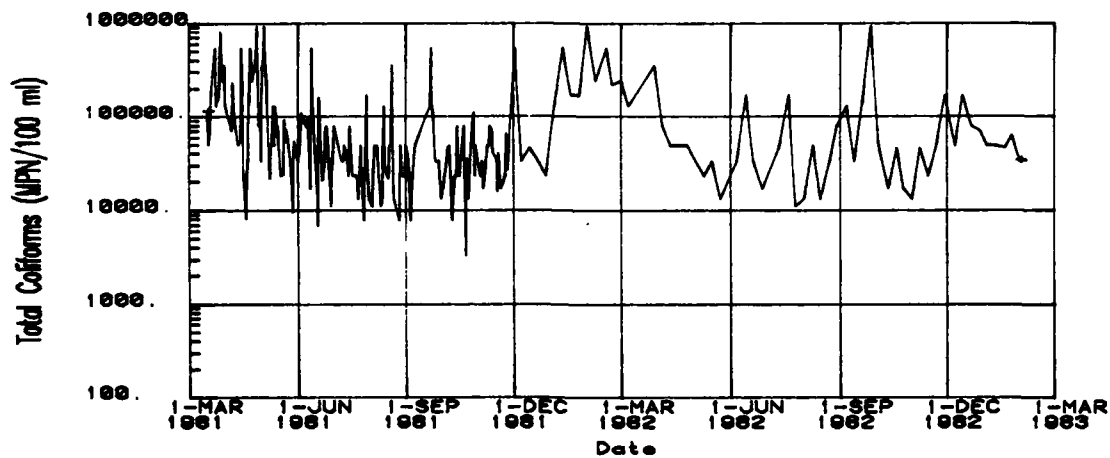


(b). Potomac Estuary Water

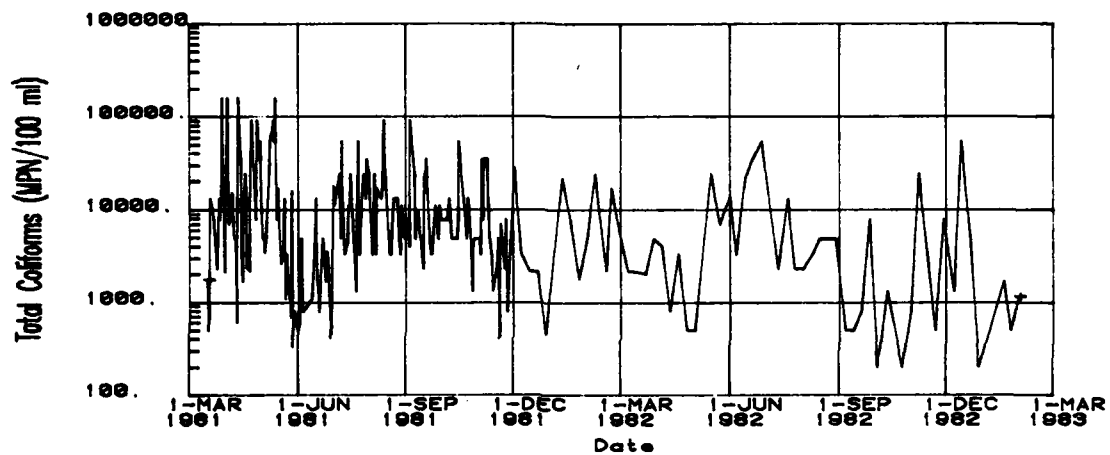


(c). EEWTP Blended Influent

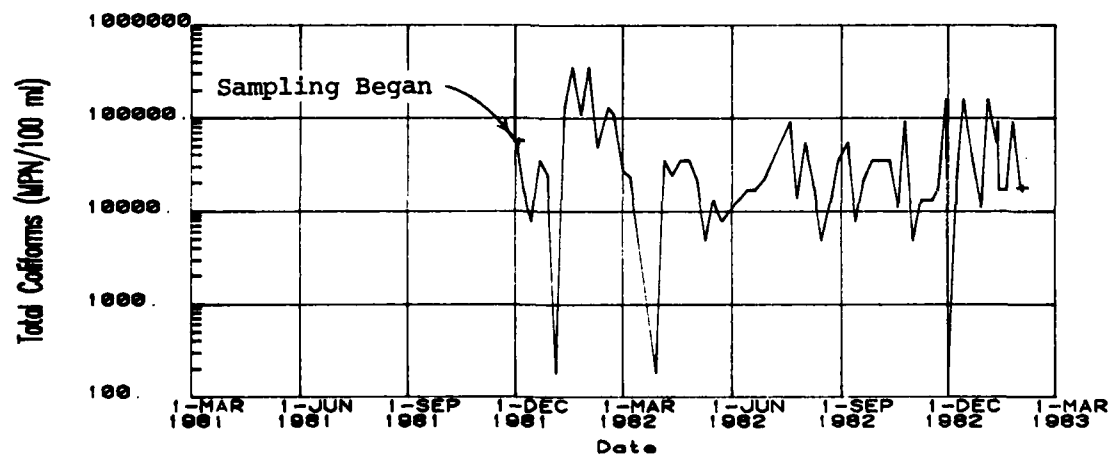
**GROSS BETA RADIATION  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-20**



(a). Blue Plains Nitrified Effluent

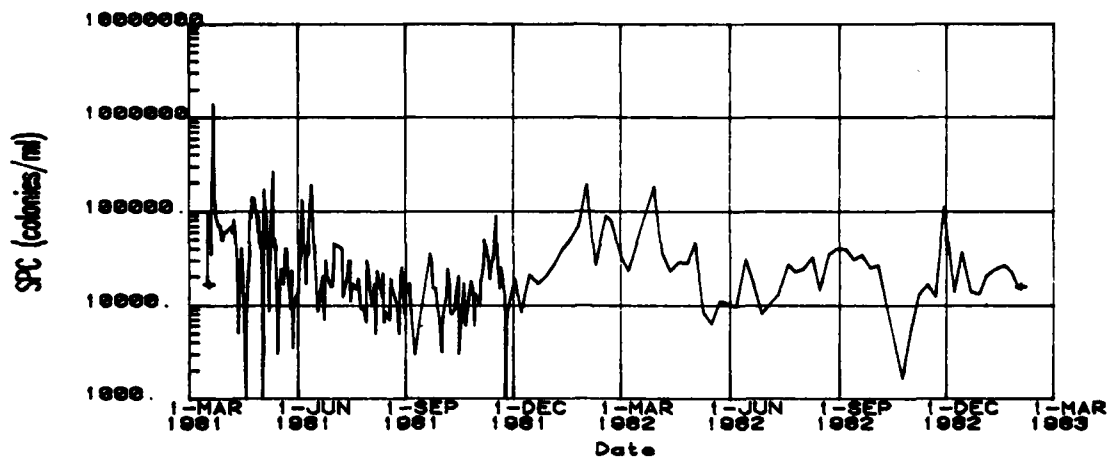


(b). Potomac Estuary Water

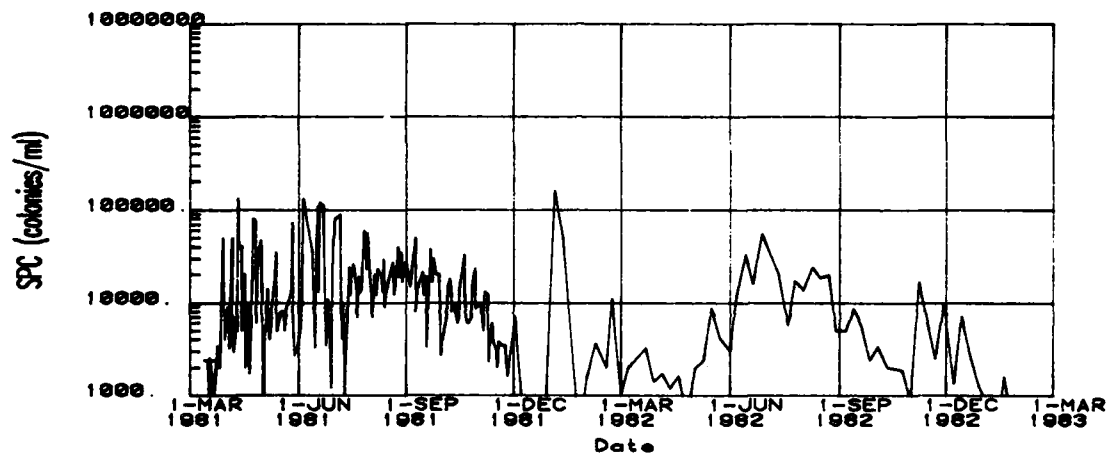


(c). EEWTP Blended Influent

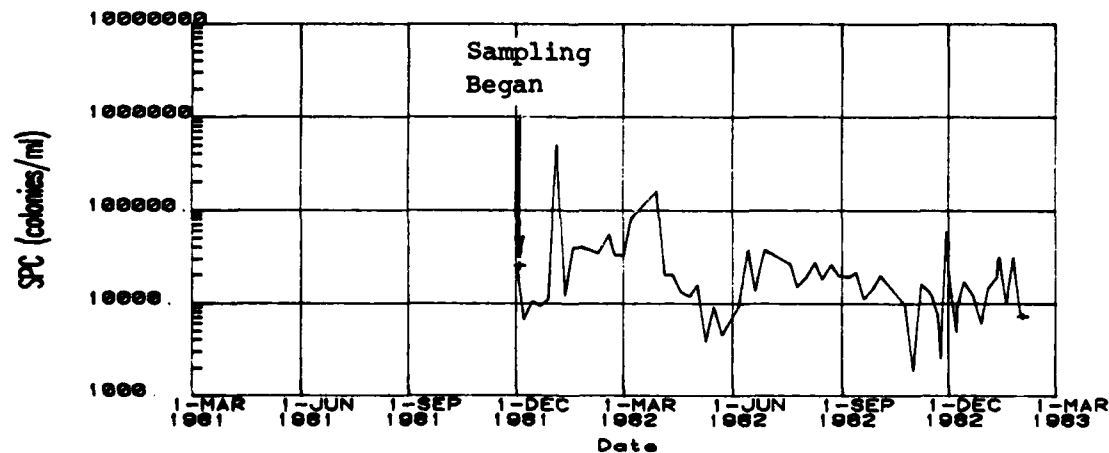
**TOTAL COLIFORMS  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-21**



(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). EEWTP Blended Influent

**STANDARD PLATE COUNT (SPC)  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-22**

**EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983**

**TABLE 6.3-4  
SOURCE CONTRIBUTIONS  
RADIOLOGICAL PARAMETERS**

<u>Parameter</u>	<u>Arithmetic Mean Blend Tank (pCi/L)</u>	<u>Source Contribution (Percent)</u>	
		<u>Blue Plains WWTP</u>	<u>Potomac Estuary</u>
Gross Alpha	0.52	49	51
Gross Beta	6.46	67	33

**TABLE 6.3-5  
SOURCE CONTRIBUTIONS  
MICROBIOLOGICAL PARAMETERS**

<u>Parameter</u>	<u>Geometric Mean, Blend Tank</u>	<u>Source Contribution (Percent)</u>	
		<u>Blue Plains WWTP</u>	<u>Potomac Estuary</u>
Total Coliform	32831 MPN/100 ml	90	10
Fecal Coliform	6343 MPN/100 ml	95	5
Standard Plate Count	16662 colonies/ml	73	27
Salmonella	0.252 MPN/100 ml	NC <sup>1</sup>	NC
Endotoxin	62.4 ng/ml	61	39

1. NC = Not Calculated.

**SELECTED ORGANIC PARAMETERS**

Because organic parameters undergo microbiological oxidation, volatilization, and/or adsorption in estuarine environments, they were not considered to be conservative and were not included in the DEM modeling efforts previously described. Thus, no RMPCs were calculated for these parameters. Measured concentrations of selected organic parameters are discussed below.

**EEWTP Influent Water Quality Monitoring**  
**March 1981 - March 1983**

Time series plots of total organic carbon (TOC) in the EEWTP source waters and blended influent are shown in Figures 6.3-23(a), (b), and (c). TOC values in the blended influent rarely fell below approximately 3.5 mg/L-C. TOC concentrations in the nitrified effluent were higher in the winter months, however no clear seasonal trends were observed for the TOC variations in the blended influent. Concentration peaks of TOC in the estuary source water correspond to peak streamflows, but these effects were dampened in the blended influent by the TOC in the nitrified effluent source.

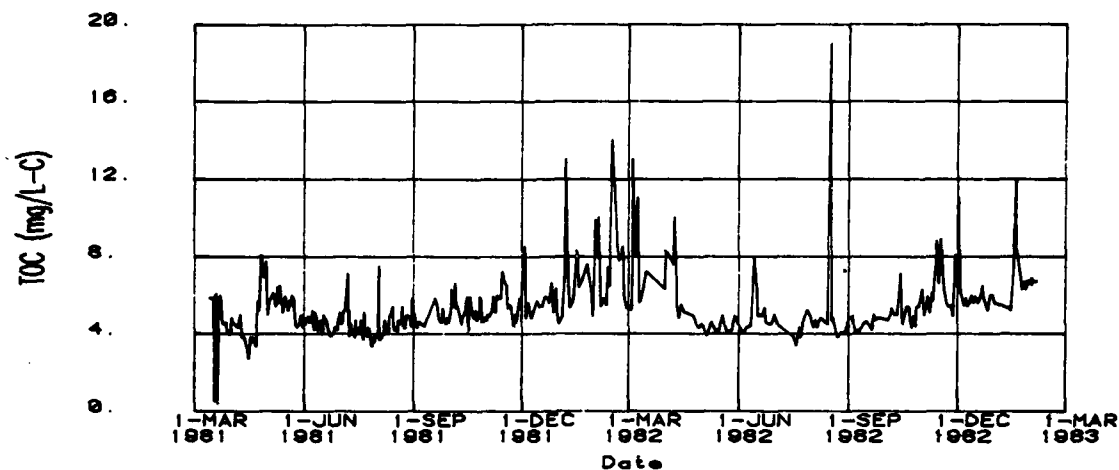
Time series plots of total organic halide (TOX) are shown in Figures 6.3-24(a), (b), and (c). Similar to TOC, no clear seasonal trends in concentration in the blended influent were observed.

Time series plots of total trihalomethane concentrations, as measured by liquid-liquid extraction (LLE), are shown in Figures 6.3-25(a), (b), and (c). The gray shaded area at the bottom of the figure represents those concentrations less than the method detection limit (MDL) of 0.2  $\mu\text{g/L}$ . Total trihalomethane concentrations in the EEWTP blended influent show higher concentrations during summer months for the two years of EEWTP operation, but never approached the MCL of 100  $\mu\text{g/L}$ .

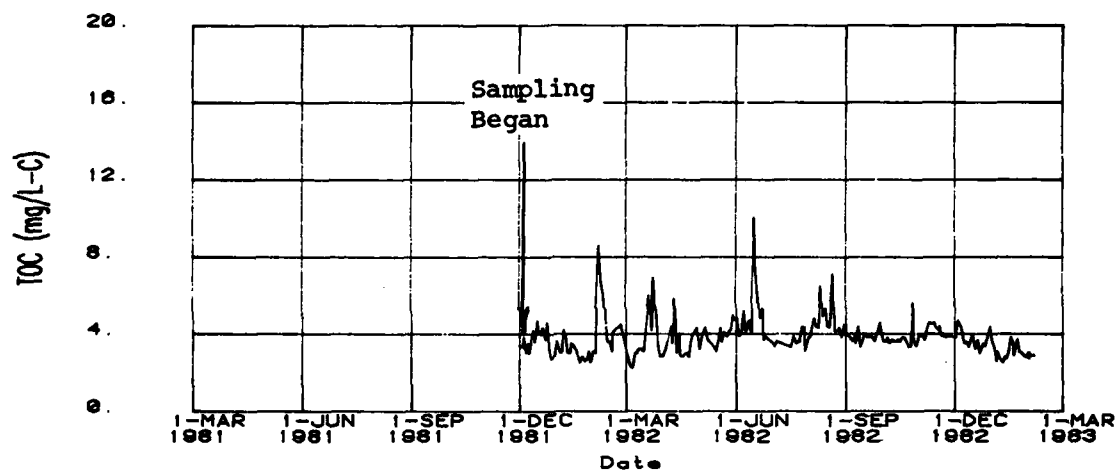
Time series plots for tetrachloroethene (PCE) concentration, as measured by LLE, are shown in Figures 6.3-26(a), (b), and (c). The gray shaded area at the bottom of the figures represent those concentrations less than the MDL of 0.4  $\mu\text{g/L}$ . As shown in Figure 6.3-26(c), tetrachloroethene in the blended influent shows seasonal variations, with higher concentrations in the winter and spring months. The lower temperatures in the nitrified effluent and estuary water decreases the effectiveness of natural aeration processes in removing tetrachloroethene.

Table 6.3-6 lists the source contributions for selected organic parameters in the EEWTP blended influent. In all cases, the fraction contributed by the Blue Plains nitrified effluent was greater than fifty percent as was anticipated. However, the observed levels of these selected organic parameters are low with respect to available health effects data and existing MCLs. The observed levels of these parameters provided a reasonable simulation of expected water quality at an estuary water treatment plant under future drought conditions and were not of sufficient magnitude to adversely affect the performance of EEWTP unit processes in removing parameters of concern.

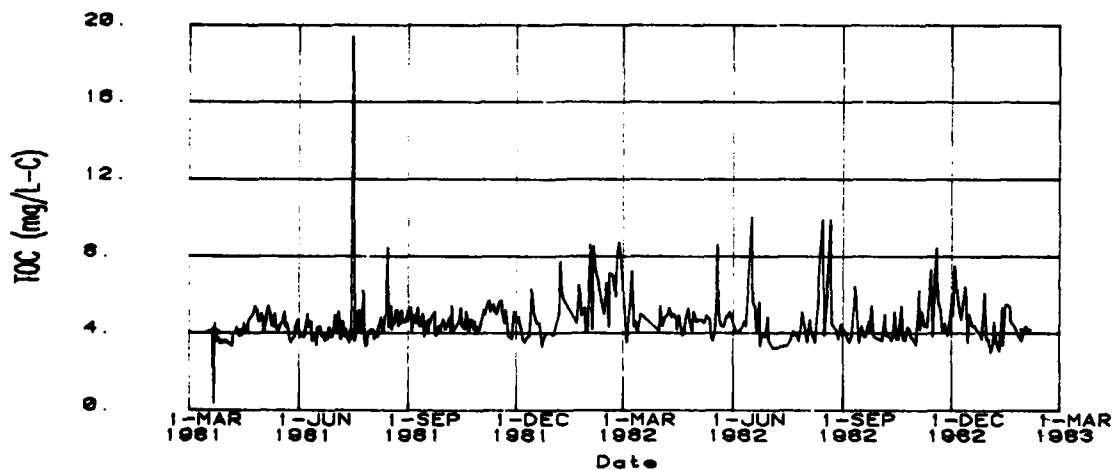




(a). Blue Plains Nitrified Effluent

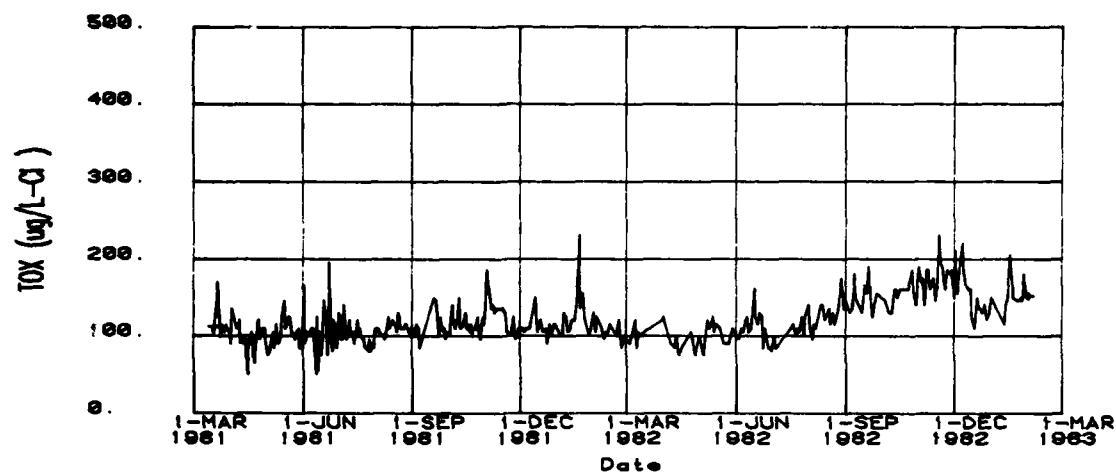


(b). Potomac Estuary Water

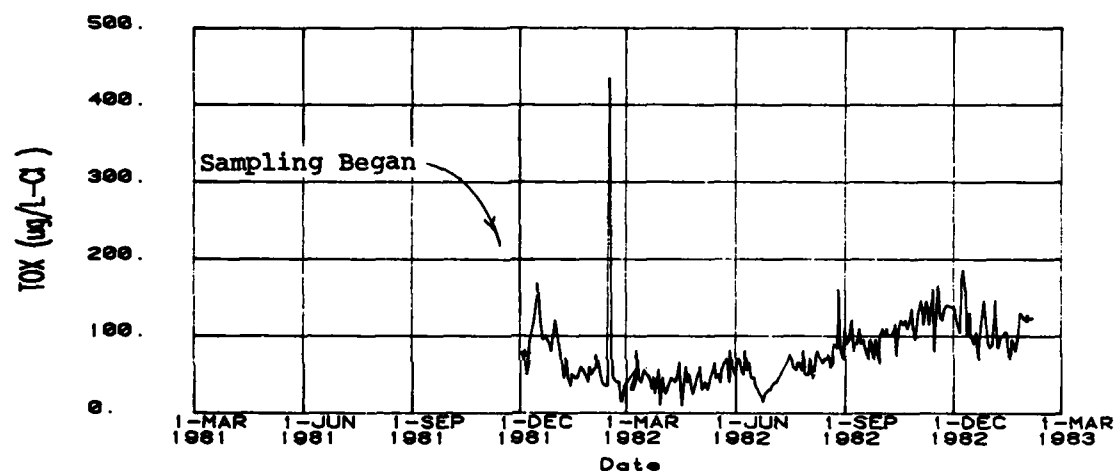


(c). EEWTP Blended Influent

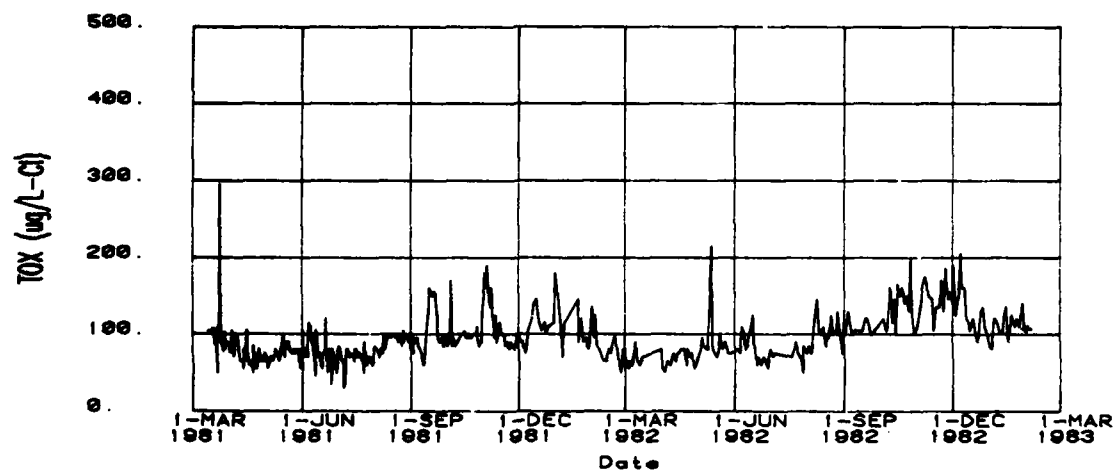
**TOTAL ORGANIC CARBON (TOC)  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-23**



(a). Blue Plains Nitrified Effluent

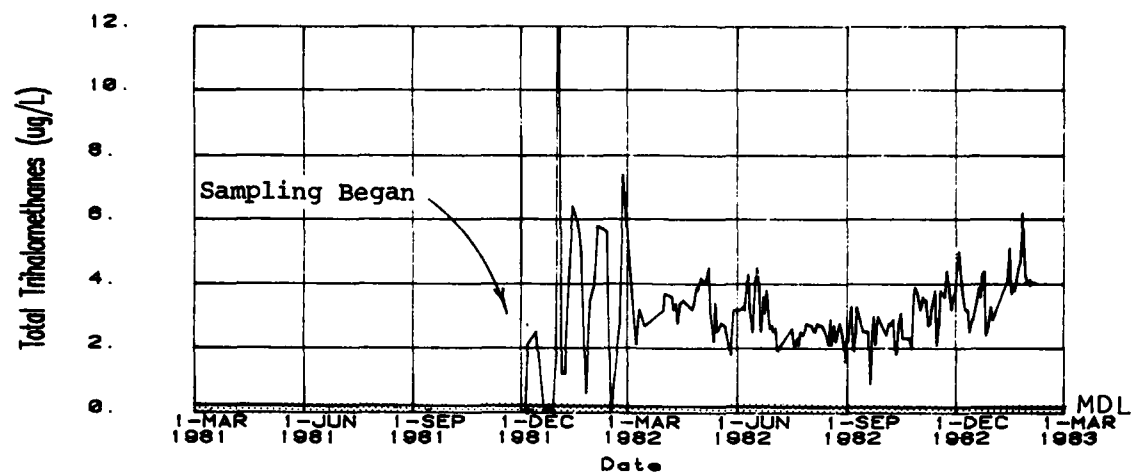


(b). Potomac Estuary Water

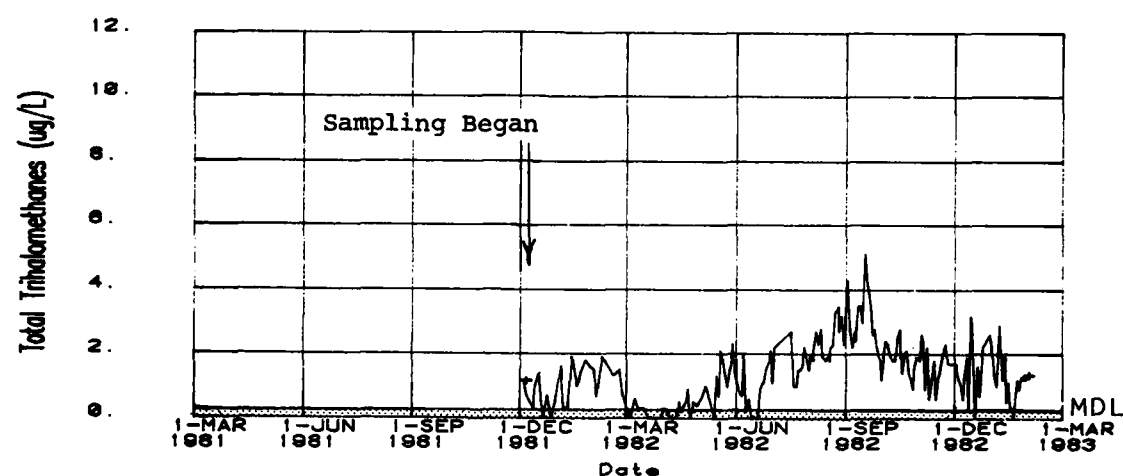


(c). EEWTP Blended Influent

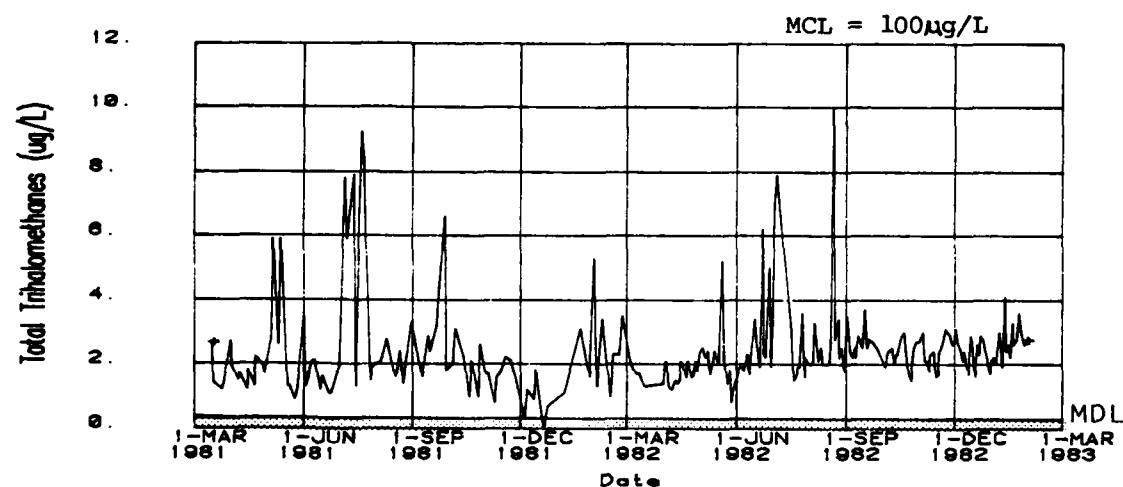
**TOTAL ORGANIC HALIDE (TOX)  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-24**



(a). Blue plains Nitrified Effluent

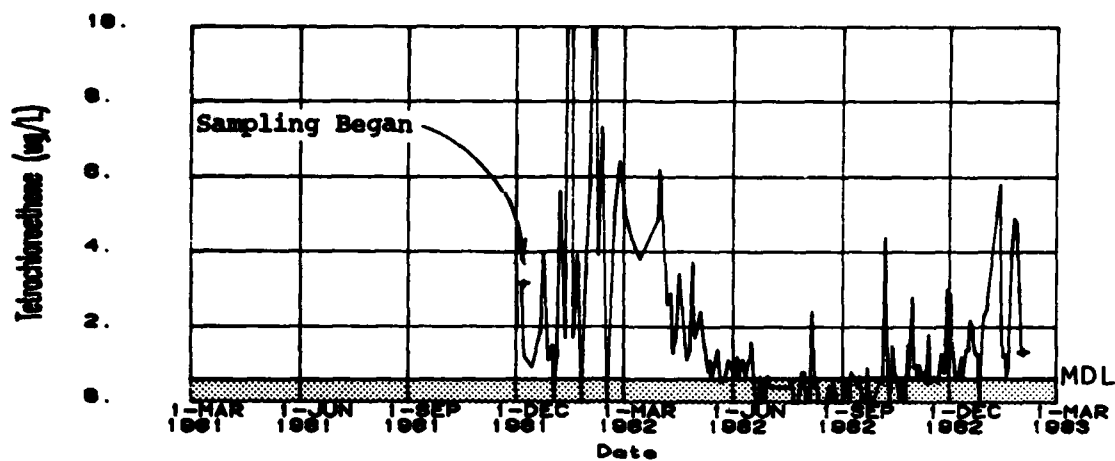


(b). Potomac Estuary Water

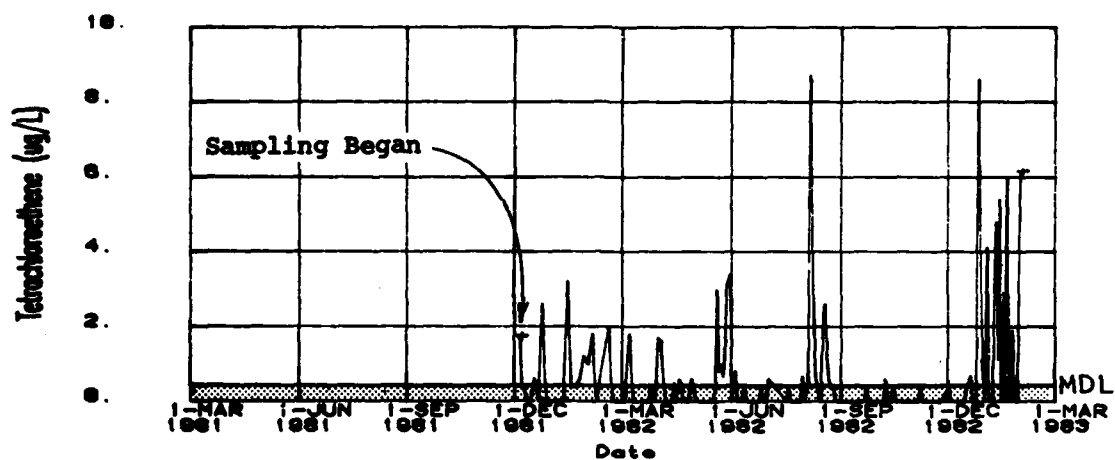


(c). EEWTP Blended Influent

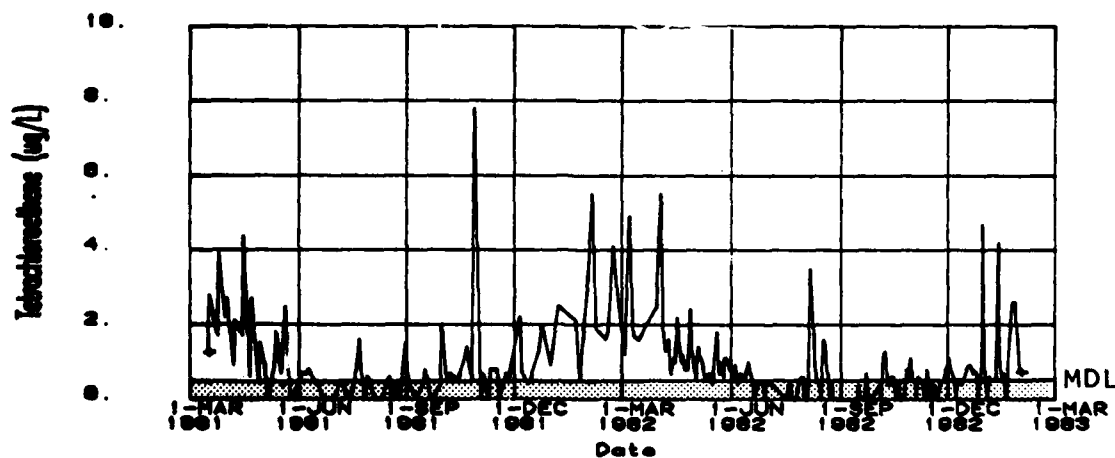
**TOTAL TRIHALOMETHANES (TTHM)  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-25**



(a). Blue Plains Nitrified Effluent



(b). Potomac Estuary Water



(c). EEWTP Blended Influent

**TETRACHLOROETHENE  
IN EEWTP SOURCE WATERS AND BLENDED INFLUENT  
FIGURE 6. 3-26**

EEWTP Influent Water Quality Monitoring  
March 1981 - March 1983

TABLE 6.3-6  
SOURCE CONTRIBUTIONS  
SELECTED ORGANIC PARAMETERS

Parameter (Method)	Geometric Mean, Blend Tank	Source Contribution (Percent)	
		Blue Plains WWTP	Potomac Estuary
Total Organic Carbon (composite samples)	4.64 mg/L-C	58	42
(grab samples)	4.57 mg/L-C	57	43
Total Organic Halide	94.67 µg/L-Cl	61	39
Total THMs (LLE)	2.43 µg/L	69	31
Tetrachloroethene (LLE)	0.97 µg/L	70	30
Trichloroethene (LLE)	0.13 µg/L	72	28

COMPARISON OF EEWTP BLENDED INFLUENT WATER QUALITY  
AMONG THREE PHASES OF OPERATION

As discussed above, certain parameters monitored at the EEWTP showed seasonal variations (e.g. - alkalinity, tetrachloroethene) or occurred at higher concentrations at certain times within the two year period of operation. These trends were described by time series plots.

Differences in influent water quality were expected to affect the quality of treated water at the EEWTP during the three phases of operation. As will be discussed in Chapters 7 and 8, all phases were of different durations and occurred during different seasons.

A qualitative comparison of the geometric means of key parameters is presented in Table 6.3-7. This table lists the geometric means for these parameters for each of the three phases. For parameters such as total coliforms, it appears that there is a difference in the blended water quality between Phases IA and IIA, where the geometric means are 63553 and 28990 MPN/100 ml, respectively. However, for TOC, where the geometric means for Phases IA and IIA are 4.50 and 4.46 mg/L-C, respectively, it appears there is little difference between these two phases.

Qualitative differences were observed for some water quality parameters among the three phases of operation. In general, for those parameters, these differences are not of sufficient magnitude to affect the performance of EEWTP unit processes. The differences between finished water concentrations for a more extensive list of parameters during the three phases of operation is discussed in Chapter 9.

**EEWTP Influent Water Quality Monitoring**  
**March 1981 - March 1983**

**TABLE 6.3-7**  
**COMPARISON OF EEWTP BLENDED INFLUENT WATER QUALITY**  
**FOR THREE PHASES OF OPERATION**

<u>Parameter</u>	<u>Units</u>	<u>Geometric Mean Concentration</u>		
		<u>Phase IA</u>	<u>Phase IB</u>	<u>Phase IIA</u>
Turbidity	NTU	11.07	15.32	8.72
Color	color units	33.7	44.9	47.3
Sodium	mg/L	29.1	22.5	30.8
Nitrogen, NO <sub>3</sub> +NO <sub>2</sub>	mg/L-N	6.90	6.66	7.72
Nitrogen, NH <sub>3</sub>	mg/L-N	0.13	0.13	0.18
Lead	mg/L	0.0016	0.0021	0.0021
Manganese	mg/L	0.1646	0.2366	0.1104
Total Coliforms	MPN/100 ml	63553	21624	28990
TOC	mg/L-C	4.50	4.63	4.46
TOX	mg/L-Cl	85.0	76.7	115.8

## **SECTION 4**

### **COMPARISON OF PROJECTED DROUGHT PERIOD WATER QUALITY WITH THE EEWTP INFLUENT**

This section compares the influent concentrations of water quality parameters in the EEWTP blended influent to the DEM modeling results reported in Section 1. This comparison indicates how well the observed EEWTP influent water quality simulated the projected estuary conditions. Comparisons to the model results are based on the Revised Maximum Projected Concentration (RMPC) which represents the maximum projected concentration based on the six month simulation of drought conditions in the year 2030 and revised use increments obtained from the monitoring program.

#### **MODELED PARAMETERS**

As discussed in Section 1, all parameters modeled using the DEM were inorganic and were assumed to be conservative in the estuary. Comparisons of the RMPC to the arithmetic mean and 90 percentile concentrations of the EEWTP blended influent, for those water quality parameters modeled using the DEM, are shown in Table 6.4-1. In all cases, at least the 90 percentile concentration, and in roughly half of the cases the arithmetic mean concentration, of the EEWTP blended influent was greater than the RMPC for these inorganic parameters. Thus, for these water quality parameters, the EEWTP influent was conservative within the assumptions used in the DEM.

#### **PARAMETERS NOT MODELED**

##### **PHYSICAL/AESTHETIC PARAMETERS**

Selection of an equal blend of nitrified effluent and estuary water resulted in an EEWTP influent with characteristics which in some cases would not be expected to match water quality in the estuary at Chain Bridge based on annual averages. As shown, the equal blend reduced the extreme values of turbidity and total suspended solids in the estuary source water, because the nitrified effluent contained a smaller proportion of these parameters. In the case of water temperature, the nitrified effluent increased the temperature of the blended influent during winter months, compared to the expected temperatures at a full-scale estuary water treatment plant. Lower temperatures would be observed in the full-scale plant due to the distance between the effluent outfall at Blue Plains WWTP and the site of the full-scale plant intake (i.e., Potomac Park or Chain Bridge). The temperature of the estuary would be increased near the outfall, but would decrease with increasing distance from the outfall due to natural processes. These two cases again illustrate the difficulties in matching expected estuary water quality under drought conditions for all water quality parameters.

Comparison of Projected Drought Period Water Quality  
With the EEWTP Influent

TABLE 6.4-1  
COMPARISON OF MAXIMUM PROJECTED WATER QUALITY PARAMETER CONCENTRATIONS  
TO OBSERVED EEWTP INFLUENT CONCENTRATIONS

1983 Revised Maximum Projected Concentration (RMPC)(mg/L) <sup>a</sup>		EEWTP Blended Influent		Comparison of EEWTP Simulation to Projected Concentrations Using the DEM
Parameter		Arithmetic Mean (mg/L)	90 Percentile (mg/L)	
<u>Major Cations, Anions, and Nutrients</u>				
Total Dissolved Solids	310	273	329	RMPC < EEWTP 90%ile
Ca	46.4	46.8	58.0	RMPC < EEWTP mean
Hardness (as CaCO <sub>3</sub> )	146.5	150.8	185.0	RMPC < EEWTP mean
Mg	7.5	8.2	10.5	RMPC < EEWTP mean
K	6.6	6.0	7.1	RMPC < EEWTP 90%ile
Na	32.0	29.5	36.9	RMPC < EEWTP 90%ile
Alkalinity (as CaCO <sub>3</sub> )	---b			
Cl	50.3	45.8	58.0	RMPC < EEWTP 90%ile
NO <sub>3</sub> -N	8.9	7.3	9.1	RMPC < EEWTP 90%ile
NH <sub>3</sub> -N	0.4	0.26 <sup>c</sup>	0.7 <sup>c</sup>	RMPC < EEWTP 90%ile
Total P	0.31	0.38 <sup>d</sup>	0.63 <sup>d</sup>	RMPC < EEWTP mean
SO <sub>4</sub>	62.2	63.5	85.0	RMPC < EEWTP mean
<u>Trace Metals<sup>e</sup></u>				
Al	---b			
Cd	0.0001	0.0002	0.0004	RMPC < EEWTP mean
Cr	---b			
Cu	0.0087	0.0450	0.0140	RMPC < EEWTP mean
Fe	1.53	1.37	2.38	RMRC < EEWTP 90%ile



**Comparison of Projected Drought Period Water Quality  
With the EEWTP Influent**

**TABLE 6.4-1 (Continued)**  
**COMPARISON OF MAXIMUM PROJECTED WATER QUALITY PARAMETER CONCENTRATIONS  
TO OBSERVED EEWTP INFLUENT CONCENTRATIONS**

Parameter	1983 Revised Maximum Projected Concentration (RMPC)(mg/L)	EEWTP Blended Influent Arithmetic Mean (mg/L)	90 Percentile (mg/L)	Comparison of EEWTP Simulation to Projected Concentrations Using the DEM
Pb	0.002	0.003	0.006	RMPC < EEWTP mean
Mn	0.194	0.197	0.340	RMPC < EEWTP mean
Hg	0.0002	0.0005	0.0004	RMPC < EEWTP Mean
Ni	--- <sup>b</sup>			
Ag	0.0007	0.0006	0.0014	RMPC < EEWTP 90%ile
Zn	0.028	0.026	0.047	RMPC < EEWTP 90%ile

- a. Assuming July - December 1930 stream flow, 2030 water demands, and intake at Chain Bridge.  
b. Revised use increments could not be calculated because concentrations in Blue Plains effluent was less than the assumed background concentrations.  
c. Blue Plains Nitrate-Nitrite concentration used.  
d. Blue Plains orthophosphate concentration used.  
e. Blue Plains concentration as measured by AAS, as opposed to ICAP, used.

## Comparison of Projected Drought Period Water Quality With the EEWTP Influent

Because droughts occur historically during the summer and fall seasons, however, the selected mix ratio was an adequate simulation with respect to the physical/aesthetic parameters. Turbidities are expected to be lower during these seasons, with extreme levels occurring during local storm events. Such events did occur during the period of EEWTP, and were observed during both winter and summer months as shown in Figure. 6.3-3.

The selected influent blend also adequately simulated estuary water temperatures during the historical period of drought conditions, summer and early fall (1 June to 1 October), as shown in Figure 6.3-5. The effects of higher water temperatures in the blended influent during winter months on EEWTP process performance are discussed in Chapter 11.

### MICROBIOLOGICAL PARAMETERS

The selection of an equal blend of nitrified effluent and estuary water resulted in a blended influent which was probably conservative with respect to this group of parameters. The major proportion of these parameters were contributed by the nitrified effluent. The expected levels of these parameters in the estuary under future drought conditions would likely be lower than those observed in the blended influent, due to decay, agglomeration, and settling of bacteria and algae in an estuarine environment. Thus, the equal blend resulted in a conservative simulation of expected levels of these parameters in an estuary water treatment plant.

### ORGANIC PARAMETERS

The selection of an equal blend of nitrified effluent and estuary water resulted in a blended influent which provided adequate levels of organic parameters. As with the microbiological parameters, the major proportion of the organic parameters were contributed by the nitrified effluent source. Because of natural processes such as microbial oxidation, volatilization, and adsorption onto bacteria and/or particulates in an estuarine environment, the expected levels of these parameters in the estuary under future drought conditions would likely be lower than those observed in the blended influent. Levels of volatile organics would be decreased through natural aeration processes, and particulate TOC would settle out. Thus, the equal blend ratio resulted in a conservative simulation.

### SUMMARY

A quantitative indication of how well the EEWTP blended influent simulated the projected drought water quality for those parameters modeled using the DEM was obtained by comparing the arithmetic mean and 90 percentile concentrations in the blended influent to the RMPC as indicated by the modeling results. In all cases, either the mean or the 90 percentile concentrations exceeded the revised maximum projected concentration. Thus, the EEWTP blended influent

## Comparison of Projected Drought Period Water Quality With the EEWTP Influent

water quality was a conservative simulation of the projected concentrations of a group of water quality parameters under future drought conditions.

The DEM water quality modeling efforts assumed that the inorganic parameters investigated behaved conservatively. That is, their concentrations were affected only by municipal use, by water and wastewater treatment, and by mixing and transport within the estuary. In estuarine environments, such as the Potomac estuary, water quality parameters are often affected by natural processes such as microbial uptake and transformation, adsorption onto solid surfaces, and coagulation and settling. Thus, the assumption of conservative behavior of these parameters provides a "worst-case" projection of water quality in the estuary under drought conditions.

The time series plots of concentration for those water quality parameters of interest presented in this chapter showed that the maximum values in the EEWTP blended influent for many of these parameters often exceeded the RMPC. However, except for ammonia, the observed concentration variations did not exceed the capabilities of the EEWTP unit processes to perform under anticipated future drought water quality conditions. In addition, the plots helped to illustrate the seasonal and streamflow related variability of several parameters. For example, tetrachloroethene concentrations are the highest during winter and spring months. As historic drought periods have often occurred during the late summer and fall in this area, the observed concentrations in the blended influent for these seasons would be more indicative of anticipated levels during drought periods.

As recognized at the beginning of EEWTP operation (JMM, 1981), it was not possible to obtain an influent blend which would exactly match the levels to be expected under drought conditions of all water quality parameters monitored. However, as shown for those inorganic water quality parameters modeled using the DEM, the use of an equal blend at the EEWTP provided a conservative simulation of the projected estuary water quality under drought conditions.

## REFERENCES

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## **CHAPTER 7**

### **PLANT PERFORMANCE - ALUM PHASE**

The objectives of this chapter are to provide a detailed description of the EEWTP treatment facilities, to describe how they were operated, and to evaluate the performance of the experimental plant and its individual unit processes. This chapter evaluates the alum mode of operation which is further divided into two phases, IA and IB.

Chapter 7 is divided into four sections. Section 1 describes the process configurations used during each operating period and provides information about design and operating criteria. Also included are brief discussions on mechanical reliability and the major operational problems encountered. Section 2 presents the overall performance of the plant with respect to the water quality parameters monitored, and Section 3 traces the fate of contaminants of interest through the plant. Section 4 analyzes the major water treatment processes used and addresses some of the primary operational issues that impact performance. Additional information on design criteria, operational details and plant performance data can be found in Appendices D, E, and G, respectively.

## **SECTION 1**

### **PROCESS OVERVIEW**

The schematic shown in Figure 7.1-1 illustrates the water treatment processes used in Phase IA and IB of plant operation. Microscreening, intermediate ozonation and carbon adsorption were included with the more conventional treatment scheme because of the anticipated levels of particulate contaminants, microorganisms and synthetic organic chemicals in the blended influent of the experimental plant.

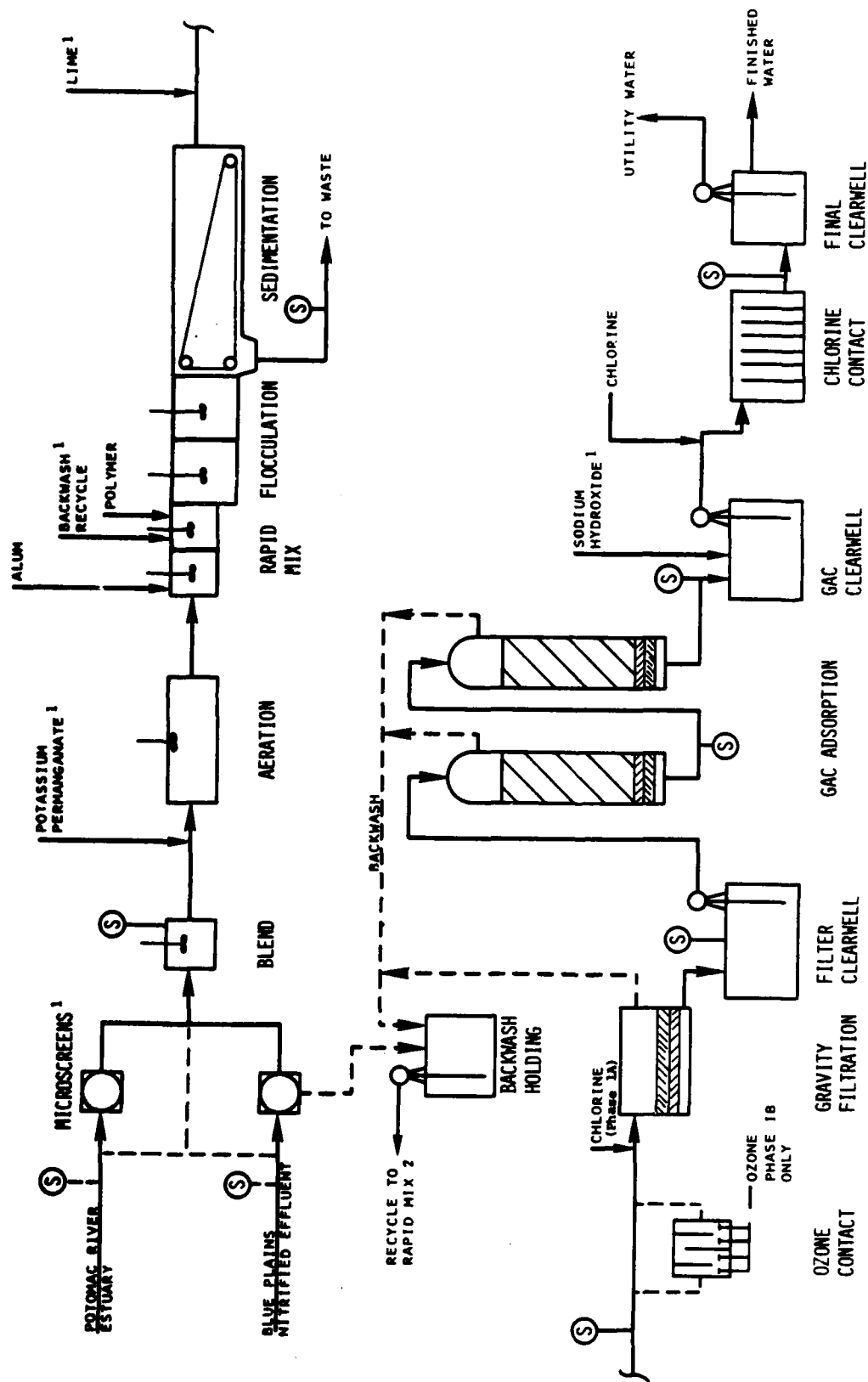
#### **PHASE IA**

The unit processes utilized in Phase IA (16 March 1981 until 16 March 1982) consisted of the following; microscreening, surface aeration, chemical coagulation and flocculation (using alum and polymers), gravity sedimentation, intermediate chlorination, dual-media gravity filtration, adsorption on granular activated carbon and disinfection using free chlorine. Table 7.1-1 provides design and operational information on Phase IA and IB.

Alum, was selected as the primary coagulant due to its widespread use in water treatment. Polymers were used to enhance chemical floc properties such as strength and settleability and to produce a water chemically conditioned for dual-media filtration. Microscreens were installed to remove algae that might proliferate in a contaminated source such as the Potomac River estuary. A need to include a barrier against synthetic organic chemicals, and to reduce levels of naturally occurring organic compounds necessitated the inclusion of granular activated carbon. Free chlorination was selected for final disinfection because it is used in two of the three local plants that were monitored for water quality comparison data, and because it is the primary drinking water disinfectant used in the United States today.

#### **PHASE IB**

Phase IB refers to the three and one-half month period of operation that began on 16 March 1982 and ended 7 July 1982. The treatment processes used in IB were identical to those in IA with the exception of intermediate disinfection. In Phase IB, ozone replaced chlorine. Ozone was selected to reduce problems encountered in Phase IA with manganese and odor. In addition, it has been postulated that use of ozone prior to filtration and GAC adsorption can improve GAC performance and lead to less frequent regeneration of the GAC. This appeared worthy of evaluation because of the high cost of GAC.



(S) SAMPLE LOCATION  
 1. SEE TABLE 7. 1-1  
 FOR OPERATING PERIODS

EEWTP PROCESS FLOW SCHEMATIC  
 (PHASES 1A AND 1B)  
 FIGURE 7. 1-1

# Process Overview

TABLE 7.1-1  
OPERATIONS SUMMARY FOR PHASES IA AND IB  
(16 MARCH 1981 THROUGH 7 JULY 1982)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Potomac River Estuary Pump Station	<p><u>Intake Pumps</u> Number: 2 Type: non-clog centrifugal Flow: 22 L/S (350 gpm) @ 20.4 m (67 ft) TDH</p> <p><u>Discharge Piping</u> Diameter: 0.2 m (8 in) Material: polyethylene</p>	<p>Operating periods: Phase IA &amp; IB</p> <p>Average daily flow: 1020 m<sup>3</sup>/day (0.273 mgd)</p> <p>When out of service, used 100% nitrified effluent</p>	<p>% Downtime: 1</p> <p>Causes: Broken discharge line Repair of flooded vacuum pump head</p>
Blue Plains Nitrified Effluent Pump Station	<p><u>Intake Pumps</u> Number: 4 Type: non-clog centrifugal Flow: 22 L/S (350 gpm) @ 26 m (85 ft) TDH</p> <p><u>Discharge Piping</u> Diameter: 0.2 m (8 in) Material: polyethylene</p>	<p>Operating periods: IA &amp; IB</p> <p>Average daily flow: 920 m<sup>3</sup>/day (0.246 mgd)</p> <p>When out of service, used 100% Potomac estuary water</p>	<p>% Downtime: 9</p> <p>Causes: Broken discharge lines Power failures</p>
Microscreens	<p>Number: 2</p> <p><u>Screen Panels</u> Material: polyester cloth Mesh size: 35 <math>\mu</math>m (0.0014 in)</p> <p><u>Drum</u> Diameter: 1.6 m (5.2 ft) Area: 6.7 m<sup>2</sup> (71.7 ft<sup>2</sup>) Speed Range: 0.3 to 9 rpm</p>	<p>Operating periods: 3/16/81 to 10/15/81</p> <p>Avg. drum submergence: 66%</p> <p>Avg. hyd. loading rate: 5 L/m<sup>2</sup>-S (7.5 gpm/ft<sup>2</sup>)</p> <p>Avg. drum speed: 5 rpm</p> <p>Avg. headloss across panel: 23 mm (0.9 in)</p>	<p>% Downtime: 23</p> <p>Causes: Faulty Drum Speed Control Board Torn Screens Routine Maintenance Process Testing Bearing Failure</p>
Precipitation Surface Aeration	<p>Type: mechanical-pitched blade vertical turbine</p> <p>Motor power: 1.5 kw (2 hp)</p> <p>Tank volume: 29.1 m<sup>3</sup> (1,030 ft<sup>3</sup>)</p> <p>Mixing energy, G: 180 sec<sup>-1</sup></p> <p>Detention time: 22 min.</p>	<p>Operating periods: IA &amp; IB</p>	<p>% Downtime: 0</p>



# Process Overview

TABLE 7.1-1 (Continued)  
OPERATIONS SUMMARY FOR PHASES IA AND IB  
(16 MARCH 1981 THROUGH 7 JULY 1982)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Preoxidation Potassium Permanganate	Manual batching, 1 to 4% solution, fed to process with small metering pump	Operating period: 6/1/81 to 1/24/82 Addition points: 6/1/81 to 6/15/81 - Rapid Mix (RM) No. 1 6/16/81 to 10/1/81 - Aeration tank 10/2/81 to 1/24/82 - Blend tank eff. Dose: 1 mg/L for entire period	% Downtime: 0
Rapid Mix	Number: 2 in series Volume ea.: 1.4 m <sup>3</sup> (49 ft <sup>3</sup> ) Detention time: 1 min each Mixing energy, G = 400 sec <sup>-1</sup>	Operating period: Phases IA & IB Addition of alum in RM No. 1 Addition of coagulant aid in RM No. 2 4 L/min carrier water added to each	% Downtime: less than 1 Causes: Replace seals in gear boxes of each unit
Coagulation Chemical Addition	Primary coagulant: liquid alum 8.3% Al <sub>2</sub> O <sub>3</sub> Coagulant aid polymers: Hercofloc 1018 (anionic) Calgon 233 (nonionic) Betz 1160 (cationic)	Alum Operating period: Phases IA & IB Avg. alum dose 54 mg/L Polymer Operating periods: See text Avg. polymer dose 0.1 to 0.25 mg/L	% Downtime: 0
Flocculation	Number of stages: 2 Volume ea.: 26.5 m <sup>3</sup> (1,800 cu ft) Det. time: 20 min  Mixers Number per stage: 2 Type: variable speed, pitched blade turbine Speed range: 30 to 100 rpm Mixing energy, G=20 to 100 sec <sup>-1</sup>	Operating period: Phase IA & IB Tapered operation Stage 1 avg. rpm: 60 Stage 2 avg. rpm: 30	% Downtime: less than 1 Causes: Replace belts Repair speed adjustment arm on variable speed drives

TABLE 7.1-1 (Continued)  
OPERATIONS SUMMARY FOR PHASES 1A AND 1B  
(16 MARCH 1981 THROUGH 7 JULY 1982)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes																		
Sedimentation	Dimensions: 5.9 m x 19.5 m (18 x 59.5 ft) Sidewater depth: 3.8 m (11.6 ft) Detention time: 4.5 hours  Surface loading rate: 19.2 m <sup>3</sup> / m <sup>2</sup> -d (470 gpd/sq ft) Weir loading rate: 78 m <sup>3</sup> /m-d (6,250 gpd/ft) Sludge collection: longitudinal cross collectors Sludge Pumps Number: 2 Type: progressive cavity Flow: 3.2 L/S (50 gpm) @ 690 Kpa (100 psi) TDH Motor Power: 7.5 kw (10 hp)	Operating period: Phases 1A & 1B Sludge withdrawal: daily - collector mechanism on 2 hours prior to pumping Sludge flow measured, sampled and sent to waste	% Downtime: 0																		
Intermediate pH Control	Hydrated bagged lime, manually batched and fed with chemical metering pump	Operating period: 9/18/81 to 7/6/82 <table><tr><th>Addition pt</th><th>Date</th><th>pH</th></tr><tr><td>aeration tank</td><td>9/18 to 10/1/81</td><td>7.0</td></tr><tr><td>rapid mix no.1</td><td>10/1 to 10/30/81</td><td>7.0</td></tr><tr><td>sed tank eff.</td><td>10/30/81 to 2/5/82</td><td>8.0</td></tr><tr><td>sed tank eff.</td><td>2/5 to 2/16/82</td><td>8.5</td></tr><tr><td>sed tank eff.</td><td>2/17/82 to 7/6/82</td><td>8.0</td></tr></table>	Addition pt	Date	pH	aeration tank	9/18 to 10/1/81	7.0	rapid mix no.1	10/1 to 10/30/81	7.0	sed tank eff.	10/30/81 to 2/5/82	8.0	sed tank eff.	2/5 to 2/16/82	8.5	sed tank eff.	2/17/82 to 7/6/82	8.0	% Downtime: 0
Addition pt	Date	pH																			
aeration tank	9/18 to 10/1/81	7.0																			
rapid mix no.1	10/1 to 10/30/81	7.0																			
sed tank eff.	10/30/81 to 2/5/82	8.0																			
sed tank eff.	2/5 to 2/16/82	8.5																			
sed tank eff.	2/17/82 to 7/6/82	8.0																			
Intermediate Disinfection/ Oxidation	See final disinfection for de- tails of feed equipment	Operating period: Phase 1A Avg. residual target: 1 mg/L total Cl <sub>2</sub> Also used for ammonia removal during February and March 1982	% Downtime: less than 1																		
Chlorine (Phase 1A)	Cl <sub>2</sub> solution injected into process water in-line prior to gravity filtration		Causes: Minor equipment modifications																		

# Process Overview

TABLE 7.1-1 (Continued)  
OPERATIONS SUMMARY FOR PHASES IA AND IB  
(16 MARCH 1981 THROUGH 7 JULY 1982)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Intermediate Disinfection/ Oxidation	Ozone Generator Type: horizontal tube Capacity: 36 kg/day (80 lbs/day) Contactor Type: 4 pass serpentine Diffusers: ceramic Detention time (total): 10.6 min	Operating period: Phase IB Ozone applied in countercurrent passes 1 and 3 Avg. Applied Dose: 3/18 to 4/20/81: 0 to 2.0 mg/L-O <sub>3</sub> 4/21 to 7/7/81: 4.0 mg/L-O <sub>3</sub> O <sub>3</sub> conc. in feed gas = 1% by weight	% Downtime: 7 Causes: Repair leaks in ozone cooling water jacket and ozone feed piping Modifications to ozone generator to reduce output
Ozone (Phase IB)			
Dual Media Gravity Filtration	Number: 2 Filter area ea: 5.6 m <sup>2</sup> (60 ft <sup>2</sup> ) Filtration rate: avg: 2 L/m <sup>2</sup> -s (3 gpm/ft <sup>2</sup> ) max: 4 L/m <sup>2</sup> -s (6 gpm/ft <sup>2</sup> ) Media Anthracite Depth: 0.5 m (20 in) Eff. size: 1.4 mm Uniformity Coefficient: 1.4 Sand Depth: 0.25 m (10 in) Eff. size: 0.5 mm Uniformity Coefficient: 1.4	Operating period: IA & IB Control mode: constant rate with automatic effluent valve control Filtration rates - see text Backwash criteria - see text Backwash Rates Low: 6.8 L/m <sup>2</sup> -min (10 gpm/sq ft) High: 11.5 L/m <sup>2</sup> -min (17 gpm/sq ft) Constant surface wash during backwash cycle (completely manual)	% Downtime: 0
Granular Activated Carbon Adsorption	Configurations: 2 pressure contactors in series EBCT ea: 7.5 min Surface loading rate: 6 L/m <sup>2</sup> -s (9 gpm/sq ft) GAC type: lignite based - ICI 816 Hydroarco 8x16 mesh	Operating period: Phase IA & IB See text for carbon specifications, type of carbon in service (virgin or regenerated), column sequence, service times, backwash criteria and procedures and exhaustion criteria.	% Downtime: 0

# Process Overview

TABLE 7.1-1 (Continued)  
OPERATIONS SUMMARY FOR PHASE IA AND IB  
(16 MARCH 1981 THROUGH 7 JULY 1982)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Final pH Adjustment	Liquid sodium hydroxide (50% solution) Dripped into GAC clearwell with process water used as carrier	Operating period: 2/18/82 to 7/6/82 Target pH: 7.5	% Downtime: 0
Final Disinfection	Chlorine Feed System Type: Standard gas Chlorinator feed from 150 lb cylinders with remote vacuum arrangement Contact Tank Configuration: serpentine Total contact time: 55 min	Operating period: Phase IA & IB Approx. Cl <sub>2</sub> Dose Period 3/16 to 4/30/81 3.5 5/1 to 12/15/81 2.2 12/15/81 to 1/31/82 3.1 2/1 to 3/15/82 wide variations due to elevated and erratic NH <sub>3</sub> levels. 3/16 to 7/7/82 3.7	% Downtime: 0 Approx. Total Residual Approx. Free Residual 1.6 1.1 1.8 1.6 2.7 2.5 2.8 2.4

1. Mixing energies, G, are approximate.
2. Detention time at average plant flow of 1,900 m<sup>3</sup>/day (0.5 mgd).

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OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
POTOMAC ESTUARY E. (U) MONTGOMERY (JAMES M) CONSULTING  
ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

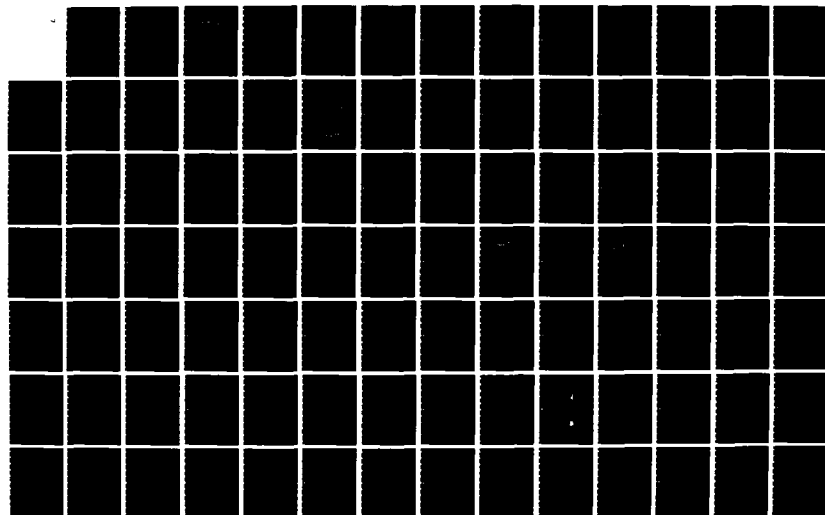
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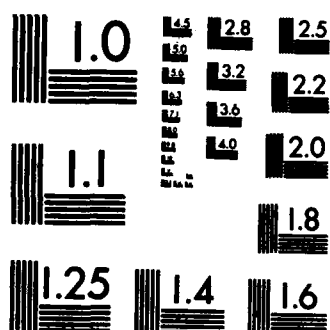
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## UNIT PROCESS DESCRIPTIONS

### INFLUENT PUMPING AND HANDLING

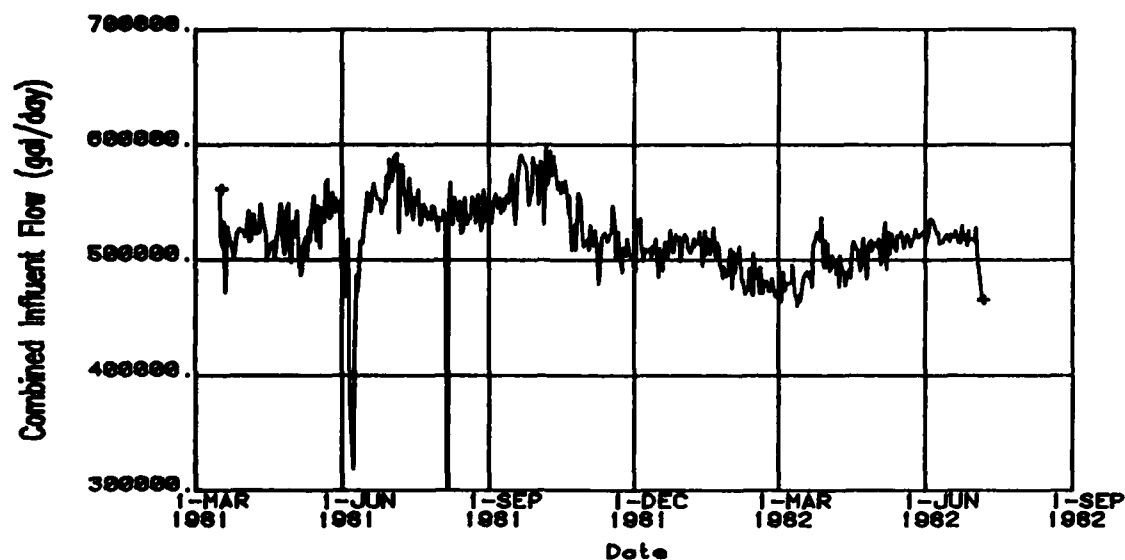
The EEWTP raw water pumping facilities were designed and constructed to deliver up to 1 MGD of any desired combination of Potomac River estuary water and unchlorinated, nitrified effluent from the Blue Plains Wastewater Treatment Plant. Estuary water was withdrawn from an intake structure located approximately 800 feet off the eastern shore of the Potomac River adjacent to the EEWTP. The intake was located at the edge of a channel at a depth of five to ten feet below the surface, depending on river stage. The Estuary Pumping Station was located on the shoreline approximately ten feet above the mean water surface elevation. It housed two centrifugal pumps, each rated at 0.5 MGD and a vacuum priming system. Suction piping was 10 in. ductile iron. The 750 ft of discharge piping that ran to the plant was 8 in. polyethelene.

Nitrified effluent was delivered to the plant via an 8 in. diameter polyethylene pipeline originating from the wet well which feeds the Blue Plains gravity filter building. This area is commonly referred to as the forebay. The line was approximately 3,000 ft long and ran across the Blue Plains plant parallel to the river. Four vertical turbine pumps, each rated at 0.25 MGD were provided at the pumping facility.

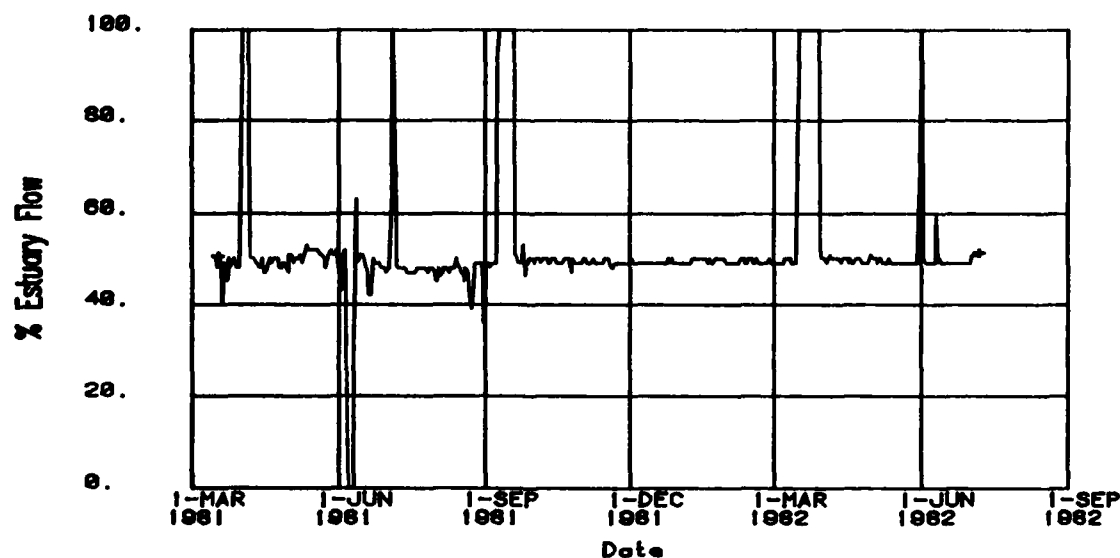
As discussed in Chapter 6 of this report, a 1:1 ratio of nitrified effluent and estuary water was chosen. A plant flowrate of 0.5 MGD was selected for the testing program to minimize chemical costs and to permit the plant to be operated at typical loading rates and hydraulic detention times.

An equal blend of influent sources was achieved during over ninety percent of the operating period covering 16 March 1981 through 7 July 1982. Six major outages occurred during this period, five affecting the Blue Plains flow and one affecting the estuary flow. These periods are shown below in Table 7.1-2. Figures 7.1-2 and 7.1-3 show the total combined flow and the percent of estuary water in the blended influent for Phases IA and IB.

During each of the Blue Plains outages, plant flow was maintained at 0.5 MGD using estuary water only. The estuary line was out of service for one five day period in June 1982. Plant flow could only be maintained at 0.37 MGD during this episode due to limitations in the flow control hardware on the line. At least one influent source was always available through the entire monitoring period.



**BLENDED INFLUENT FLOW  
(PHASES 1A AND 1B)  
FIGURE 7.1-2**



**PERCENT ESTUARY FLOW IN BLENDED INFLUENT  
(PHASES 1A AND 1B)  
FIGURE 7. 1-3**



## Process Overview

TABLE 7.1-2  
EEWTP INFLUENT INTERRUPTIONS

<u>Estuary Source</u>	
<u>Dates</u>	<u>Cause</u>
6/6/81 to 6/11/81	Broken supply line
<u>Nitrified Effluent Source</u>	
4/1/81 to 4/6/81	Local power failure
7/4/81 to 7/7/81	Broken supply line
9/8/81 to 9/19/81	Broken supply line
11/17/81 to 11/18/81	Flow control valve problems
3/15/82 to 3/29/82	Broken supply line

### MICROSCREENS

Microscreening was the lead unit process in the sequence used for the first seven months of Phase IA. The two units provided were identical and were originally installed for the purpose of removing suspended particulate matter and some microorganisms including algae.

Piping to the microscreens was configured so that they could be operated in any of the following ways:

1. Parallel, each dedicated to a single source water.
2. Individually, one microscreen filtering the entire blended influent.
3. By-passed completely.

While in service, the screens were most frequently operated in mode two. Each unit operated under gravity flow and was capable of fully automatic operation including continuous backwash. The filter fabric consisted of monofilament polyester screen with 35  $\mu$ m mesh openings. Twenty screen panels were fitted around the periphery of each rotating microscreen drum.

The units were prone to mechanical difficulties and were out of service frequently. Major mechanical problems included: torn screen panels, failure of the power control board and tachometer generator (both necessary for automatic drum speed control) and locking-up of the drum babbit bearing. The last problem was attributed to the accumulation of sand, grit, and rust in the unit during idle time.

As discussed above, the microscreens were originally installed for the purpose of removing suspended solids and algae. However, the results of a study undertaken midway through the first year indicated that the microscreens provided little, if any, benefit to downstream processes. The study showed that

## Process Overview

solids captured by the microscreens could be removed in the sedimentation and filtration processes which followed. The increased solids loading of larger particles without microscreening appeared to enhance the effectiveness of the coagulation/flocculation process by providing more contact opportunities during floc development and agglomeration. Removal of algae by the microscreens was not evaluated during the study, as algae were not abundant in the influent. The microscreens were permanently removed from service on 19 October 1981.

Specific details regarding microscreen performance and results of the study can be found in Appendix I, Section 10.

### PREOXIDATION - SURFACE AERATION

Aeration provides a mechanism for the exchange of volatile substances between air and water. The concentrations of objectionable parameters such as hydrogen sulfide, carbon dioxide and certain volatile organic chemicals may be reduced by this process. The entrainment of air in raw water increases the dissolved oxygen content which can, under the proper conditions, oxidize certain inorganic compounds and elements including Fe(II) and Mn(II).

The surface aerator was a constant speed, 2 hp, four blade turbine type which provided a mixing energy,  $G$ , of approximately  $180 \text{ sec}^{-1}$ . The detention time in the aeration basin, which preceded the rapid mix tanks, was roughly twenty minutes at a process flow of 0.5 MGD. The surface aerator was in service through Phase IA and IB without any mechanical problems and required little operational attention.

Results of a study, conducted during Phase IA, to determine the effectiveness of surface aeration for removal of volatile organic compounds can be found in Appendix E, Section 4.

### PREOXIDATION - POTASSIUM PERMANGANATE

Potassium permanganate ( $\text{KMnO}_4$ ) was chosen for use as a manganese control measure. Its high oxidation potential and purported ability to rapidly oxidize soluble manganese Mn(II) to the insoluble, filterable Mn(IV) state in the neutral pH range made  $\text{KMnO}_4$  the most reasonable control measure available at the EEWTP under the operating conditions chosen for Phase IA.

The  $\text{KMnO}_4$  system was operated from 1 June 1981 through 24 January 1982, and consisted of a 1,000 gallon tank on which was mounted a small mixer used to prepare a one percent  $\text{KMnO}_4$  solution from  $\text{KMnO}_4$  crystals. A small chemical metering pump fed the solution to the process at a constant dose of 1 mg/L throughout the entire operating period. Table 7.1-1 shows the operating history of the  $\text{KMnO}_4$  feed process including changes in the application point. Results of the various manganese control measures and special speciation studies can be found in Chapter 10 and Appendix I, Section 6.

## Process Overview

### CHEMICAL CLARIFICATION

The primary objective of the chemical clarification process was the removal of particulate material and associated adsorbed and entrapped contaminants such as microorganisms, asbestos, heavy metals and organic matter. The EEWTP chemical clarification process consisted of three major elements: coagulation - chemical addition at the rapid mix tanks for particle destabilization and enmeshment; two stage flocculation - for the gentle agitation of the destabilized particles to enhance particle formation; and sedimentation - where the solids formed during flocculation were removed by gravity settling. Each component of the clarification process is discussed in greater detail below.

#### Coagulation

The primary coagulant was aluminum sulfate (alum). The fifty percent alum solution was added to the process at rapid mix tank number one by way of a 0.5 in. diameter injector tube. Carrier water (finished water) at the rate of 1 gpm was added to the fifty percent alum at the pump discharge to enhance mixing. The alum dose averaged 54 mg/L as  $\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{H}_2\text{O}$  and ranged from 19 mg/L to 76 mg/L during this operational period.

Polymer, used in small dosages (<0.5 mg/L) as a coagulant aid to enhance floc settleability and strength, was introduced into the process water at rapid mix tank number two. The polymers used, average doses, and operating periods are given in Table 7.1-3.

TABLE 7.1-3  
POLYMER USAGE

<u>Polymer</u>	<u>Type</u>	<u>Average Dose (mg/L)</u>	<u>Operating Period</u>
Hercofloc 1018	Slightly anionic	0.15	Mar to Oct 1981
Betz 1160P	Cationic	0.20	Oct to Nov 1981
Calgon 233	Non-ionic	0.25	Nov 1981 to July 1982

The polymers listed were in powder form. A 0.1 percent polymer solution was prepared manually and fed to the process by a small metering pump. Carrier water was also added at the pump discharge. Plant finished water was used for make-up and carrier for the first nine months of operation. However, because chlorine can oxidize polymers with resulting loss in effectiveness, a change was made to use gravity filter effluent water as the carrier water.

The vertical turbine rapid mix units, which performed the critical function of initial dispersion of chemical into the process stream, were identical and provided a velocity gradient, or mixing energy,  $G$ , of approximately  $400 \text{ sec}^{-1}$ . The mean detention time in each tank was approximately one minute at the average plant flow of 0.5 MGD.

## Process Overview

The alum coagulation process was operated with the primary goal of maximizing turbidity and TOC reduction. In an effort to optimally achieve these goals, several control strategies were tried to determine optimum coagulant doses. These strategies were closely tied to an on-going series of bench-scale jar tests which are discussed in Chapter 10, Section 2 and Appendix I, Section 1.

Initially, the operational coagulant dosing program for the plant consisted of one jar test, run daily at 0300 hours with dose selection made on the basis of turbidity removal. Blend tank water without pH control and a constant polymer dose were used.

In July 1981, a second program was instituted. The second dosing program consisted of a jar test per operational shift, one at 0300 hours and another at 1700 hours. Blend tank water was used without pH control and with a constant polymer dose. The parameters measured were turbidity, UV absorbance at 254 nm, pH, and temperature. Dose selection was based on turbidity, UV results, and an established protocol from previous jar testing data. UV had been correlated to TOC and, therefore, was used as a surrogate parameter for TOC.

A third coagulant dosing program, begun in late September 1981 consisted of a daily 0300 hour jar test only. Alum dose selection followed the procedures established for the second dosing program. In the event that the sedimentation tank effluent turbidities exceeded 4 NTU during the daytime shift, an additional jar test was conducted with dose selection based solely on turbidity. This program was continued into January 1982.

Full-scale operating experience showed that an alum dose of at least 40 to 50 mg/L was required to approach the maximum attainable level of TOC removal. TOC removals would increase with increasing dosages, but beyond 50 to 60 mg/L, the additional removal was minimal and not cost-effective. Secondary problems, such as excessive pH depression and large chemical sludge volumes, would also result from excessively high dosages. From January 1982 through Phase IB, the plant was operated at a constant alum dose of approximately 50 mg/L. Plant turbidity and TOC measurements were analyzed daily to check on the system. Jar tests, using a wide range of alum doses with direct measurement of TOC, were conducted weekly or as needed to ensure that this dose range was near the optimum.

The chemical feed and rapid mix systems functioned properly through the entire period. Downtime was insignificant and was caused by process modifications and minor repair to the rapid mix gear boxes.

### Flocculation

The two-stage flocculation process consisted of identical basins and mixers. Each basin had a detention time of twenty minutes at a flow of 0.5 MGD. Two variable speed, pitched blade vertical turbine mixers were used in each stage. Each mixer had an impeller speed range of 33 to 100 rpm. During the alum phase of operation, the flocculation process was operated in a tapered fashion with the first and second stage averaging 60 and 35 rpm, respectively. The

## Process Overview

process functioned throughout the entire period without any significant problems or downtime.

### Sedimentation

The sedimentation basin had a volume of 12,400 ft<sup>3</sup>. At a flow of 0.5 MGD, the mean detention time was approximately 4.5 hours, the horizontal velocity was 0.22 fpm, with an overflow rate of 470 gpd/ft<sup>2</sup>. Two weirs serviced the basin and provided a combined weir overflow rate of 6,250 gpd/ft (actual characteristics were somewhat less than theoretical as discussed in Chapter 10 and in Appendix I, Section 10). A longitudinal conveyor was used for sludge collection. The sludge was pumped out of the basin with a fixed speed progressive cavity sludge pump. A second pump was available as a back-up. Each pump had a flow capacity of 50 gpm.

The only process variable associated with the sedimentation process was sludge withdrawal. For the purpose of solids determination and metals analyses, sludge was removed from the tank on a daily basis. The sedimentation underflow was pumped from the basin collection trough to the sludge storage and recarbonation tank for approximately 45 minutes each morning. The sludge was then mixed in the storage tank to achieve a relatively homogeneous mixture for sampling. From the storage tank, the sludge was pumped to a sanitary sewer. The sludge sample was taken from the pump discharge midway through the wasting process. Approximately 2,500 gal of sludge were pumped daily.

### INTERMEDIATE PH CONTROL

The pH of the blended raw water entering the EEWTP averaged 7.0 during Phase IA and was relatively low in alkalinity (approximately 60 mg/L as CaCO<sub>3</sub>). The addition of alum in coagulation and chlorine in intermediate and final disinfection caused further reduction in alkalinity and pH, resulting in a corrosive water, based on the Langelier Index of calcium carbonate saturation. To compensate for the alkalinity destruction caused by chemical treatment and to reduce the potential for corrosion, pH adjustment using lime was begun in September 1981.

Initially, enough lime was added to compensate for the alkalinity destruction and pH depression caused by alum coagulation. The target pH in the sedimentation basin effluent was 7.0 through November. In December, the target pH was raised to 8.0 in an attempt to achieve a more favorable Langlier Index in the finished water. This practice continued until early February 1982, when it became necessary to increase the target pH to 8.5 to offset the pH reduction caused by the high chlorine doses required for ammonia control.

The original lime addition point was the aeration basin which was chosen to enhance permanganate oxidation of soluble manganese prior to the coagulation process. However, due to poor mixing in this tank, the application point was moved to the first rapid mix tank on 1 October 1981. The elevated pH through the coagulation process during this period resulted in significantly less TOC

## Process Overview

removals and the application point was moved to the sedimentation tank effluent trough on 30 October 1981 where it remained throughout Phase IA and IB.

Because relatively small amounts of lime were required for pH control, production of lime slurry from the lime slaking facilities was impractical. Therefore, a small lime make-up and feed system was fabricated. Lime slurry was prepared manually from bagged hydrated lime and was fed to the process with a small metering pump. Control was achieved by maintaining a target pH in the process. A small mixer was installed in the sedimentation trough to aid mixing.

### INTERMEDIATE DISINFECTION/OXIDATION - CHLORINE

Intermediate disinfection with chlorine was used primarily to keep the gravity filters free from excessive biological buildup and fouling. The process was also used for ammonia control during February and March 1982.

The chlorination system used for intermediate disinfection was identical to that used for final disinfection except that operation was manual, and there was no residual chlorine analyzer or recorder provided. The chlorine solution was fed in-line prior to gravity filtration, bypassing the intermediate disinfection tank. A more detailed description of the chlorination equipment can be found under the final disinfection section of this Chapter and in Appendix D.

A total chlorine residual of 1.0 mg/L was maintained prior to gravity filtration. Grab samples were taken every four hours to verify the residual. This total chlorine residual required an applied chlorine dose of approximately 1.5 mg/L.

Several operating schemes were used during the period of high influent ammonia concentrations, which occurred late in the first year of operation. To study ammonia removal by chloramine production and subsequent reduction on GAC, several  $\text{Cl}_2$  to  $\text{NH}_3$  mass ratios were used. This resulted in chlorine doses ranging from 2 to 15 mg/L. When intermediate breakpoint chlorination was employed during late February and early March, doses were even higher. In all, chlorine/ammonia ratios from 3:1 to 10:1 were tested in plant operations. Plant operators controlled the process by measuring the influent ammonia concentration using a specific ion probe and adjusting the chlorine feed according to a specified algorithm. Additional discussion of ammonia removal is presented in Section 3 of this chapter.

### INTERMEDIATE DISINFECTION/OXIDATION - OZONE

Ozone is a very powerful oxidant/disinfectant and it is finding increasing use in the water and wastewater treatment industry. Ozone can be used at various stages of treatment for a variety of purposes ranging from predisinfection to oxidation of taste and odor compounds. The major reasons for using intermediate ozonation at the EEWTP included:

## Process Overview

1. Disinfection - ozone was an additional barrier for destruction of microbial contaminants.
2. Oxidation of soluble and organically bound manganese for subsequent removal on the gravity filters.
3. Oxidation of naturally occurring organic compounds (e.g., humics) into component compounds potentially more amenable to biological degradation and/or adsorption on the granular activated carbon.

Ozone is extremely unstable and toxic and, therefore, must be produced on-site and applied in a closed system. The ozone generator provided at the plant was a horizontal tube, corona discharge type, capable of producing up to 80 lbs of ozone per day from air. The maximum concentration of ozone produced from the unit using air as an oxygen source was approximately 1 percent by weight. The intermediate ozone contact tank was a four pass, vertically baffled system with porous ceramic diffusers located in each pass. The tank was configured to allow any desired gas flow to be fed and metered to any combination of pass(es) with hand valves and rotometers. Offgas from the contact tank was passed through a high temperature burn-off unit to thermally decompose any ozone before discharge to the atmosphere.

The intermediate ozone process was operated from 17 March to 7 July 1982. During the first month of operation, the applied ozone dose was approximately 2.0 mg/L. From late April through the remainder of Phase IB, the applied dose was maintained at 4.0 mg/L. Results of ozone off gas testing indicated that approximately seventy percent of the applied ozone dose was absorbed.

Ozone was introduced into the contact tank at countercurrent passes one and three with two-thirds of the applied dose being fed to pass one and the remaining one-third in pass three. This dosing scheme was chosen to take advantage of the increased transfer efficiency of countercurrent flow and the larger mass-transfer potential (driving force) encountered in pass one with the unoxidized, chemically clarified water. The total gas flow being introduced into the liquid stream was approximately 20 SCFM. This provided a volumetric air to liquid ratio of roughly 0.3 in pass one and 0.15 in pass three.

Two significant problems were found with the ozone generator and contact system shortly after start-up in March. These included numerous small leaks in the 200 ft of piping between the ozone generator and contact tank, and a leaking cooling water jacket inside the ozone generator vessel. These problems were corrected during the first week of April.

## GRAVITY FILTRATION

The EEWTP gravity filtration process consisted of two identical dual media filters, each having a surface area of 60 ft<sup>2</sup>. The top layer of this filter bed was composed of 20 in. of anthracite media (effective size approximately 1.0 mm). The anthracite was supported by 10 in. of silica sand (effective size

## Process Overview

approximately 0.5) which in turn rested on 12 in. of graded support gravel. The underdrain and bed support system was composed of Wheeler filter bottoms.

The filters were operated at a constant rate by automatic operation of the effluent control valves. The depth of water above the filter bed surface was maintained between 5 to 6 ft at all times during normal operation. Except for one week in March 1982 and the last month of operation of Phase IB influent flow was split evenly between the filters during Phase I. This was equivalent to an average unit flow rate of approximately 3 gpm/ft<sup>2</sup> with both units on-line and 6 gpm/ft<sup>2</sup> with one unit on-line.

Throughout Phases IA and IB, backwashing of the gravity filters was initiated when any of the following criteria were exceeded:

1. Filter effluent turbidity approached or exceeded 0.5 NTU for two consecutive readings.
2. Headloss approached or exceeded sixty percent of available head, approximately 6 ft of water.
3. Three days passed since the last backwash.

Of these criteria, number three occurred most frequently; however, all were exceeded at times.

Backwash facilities consisted of twin, vertical turbine backwash supply pumps, each capable of delivering 1,200 gpm at 30 ft total dynamic head (TDH), and two surface wash arms per filter driven by a vertical turbine pump rated for 60 gpm at 160 ft TDH. All valving and flow throttling was pneumatically operated.

Filter effluent was used for filter backwashing and was taken from a 7,750 ft<sup>3</sup> clearwell located below and adjacent to the gravity filter structure. This clearwell also served as a reservoir for GAC feedwater.

The backwash operation was controlled manually and consisted of the following steps:

1. Start surface wash agitator.
2. Backwash at low rate, 10 gpm/ft<sup>2</sup>, for three minutes.
3. Increase backwash flow to high rate, 16 to 18 gpm/ft<sup>2</sup>, for ten minutes or until backwash water cleared.
4. Stop surface wash and gradually decrease backwash rate to restratify media. Approximately 12,000 gallons were used for each filter backwash. This was equivalent to a unit rate of 200 gal/ft<sup>2</sup>.



## Process Overview

For the first eight months of operation wash water from the filter was wasted from the backwash holding tank to the sewer. From November 1981 through the end of Phase IB, this water was pumped to rapid mix tank one for recycling. Backwash water was diverted to a holding tank from which it was pumped to recycle at between 20 to 40 gpm on an intermittent basis.

The gravity filters operated throughout Phase IA and IB without any downtime. Only the instrumentation required maintenance, and this involved routine preventive maintenance checks and calibrations.

An anthracite media loss of approximately ten percent was measured over the fifteen month period. The losses probably occurred during backwash from localized flow surges, operator error during flow rate adjustment and air entrained in the backwash water carrying media over the drain weir.

### GRANULAR ACTIVATED CARBON

Throughout Phases IA and IB, the carbon adsorption process was operated using two downflow columns in series. Each column had a 7 ft diameter and an overall height of 16.75 ft. The carbon media was supported on 12 in. of layered gravel which rested on Leopold filter tiles. Carbon bed depth averaged approximately 9 ft during the operating period. This provided an empty bed contact time (EBCT) of 7.5 minutes per column or fifteen minutes total at the nominal plant flow of 0.5 MGD. The hydraulic loading rate under these conditions was 9 gpm/ft<sup>2</sup>.

The granular activated carbon (GAC) used during Phase IA and IB was Hydrodarco 816, an 8x16 mesh lignite based carbon manufactured by ICI Americas. The properties and specifications of this carbon are given in Section 4 of this Chapter.

Operation of the GAC process consisted of the routine monitoring of several physical and chemical parameters and column backwashing when required. Every two hours, operations personnel checked the GAC influent feed flow and pressure, differential pressure across each column, influent and effluent clearwell levels, and pH and turbidity across the process. Dissolved oxygen (DO) measurements before and after each column were taken once per day.

Four criteria were originally used to initiate column backwashing. These included headloss in excess of 21 ft of water, DO consumption greater than 2 mg/L through one column, effluent turbidity greater than 0.5 NTU for more than twelve hours, or an arbitrary frequency of once every five days. Only the five day criterion was ever used, and in November 1981, it was dropped. This was done to reduce the frequency of bed disturbance caused by backwashing. This change in procedure reduced the backwash frequency to approximately one backwash per column per month. Headloss was the backwash criterion most frequently exceeded after the change.

The backwash procedure remained the same throughout the operation period and consisted of expanding the bed by 25 to 30 percent with a backwash rate of

## Process Overview

approximately 17 gpm/ft<sup>2</sup> for a period of ten minutes. Surface agitators were employed for the first five minutes of backwash. During backwash, the entire process flow was routed through the other column.

Both virgin and regenerated carbon were used during Phases IA and IB. The usage sequence and column configurations are shown in Table 7.1-4. From startup on 16 March through 25 October 1981, virgin carbon was used exclusively in both contactors. From 25 October through 16 March 1982, regenerated carbon with approximately ten percent virgin GAC for makeup was used. Through the entire Phase IB period, two columns of fully regenerated carbon were used.

TABLE 7.1-4  
GAC TYPE AND COLUMN CONFIGURATION  
PHASES IA AND IB

<u>Period</u>	<u>Column Sequence</u>	<u>Carbon Type (Lead Col/Lag Col)</u>
<u>IA</u>		
3/16/81 to 6/15/81	1,2	Virgin/virgin
6/16/81 to 8/29/81	2,3	Former lag col/virgin
8/30/81 to 10/25/81	3,1	Former lag col/virgin
10/26/81 to 3/30/82	1,2	Regenerated/regenerated
<u>IB</u>		
3/31/82 to 7/6/82	2,3	Regenerated/regenerated

GAC service life was determined primarily by effluent total organic carbon (TOC) and finished water total organic halide (TOX) values. The finished water TOC and TOX goals were 3 mg/L and 150 µg/L, respectively. To ensure these goals were achieved, GAC was replaced when effluent TOC values consistently exceeded 2 mg/L for a one to two week period, or when TOC removal reached an apparent steady state level of removal. A detailed evaluation of GAC performance is presented in Section 4 of this Chapter.

Regeneration of EEWTP spent carbon was done at ICI Americas' Darco Experimental Laboratories in Marshall, Texas. Two loads, or approximately 40,000 lbs, of GAC were regenerated. The spent GAC was transported to the ICI plant by a private contractor who specialized in GAC hauling. Reactivation of the spent carbon was accomplished in a single tube rotary kiln furnace. The same carbon initially sent for regeneration was returned to the EEWTP for subsequent use. Details concerning regeneration alternatives and the regeneration process are given in Appendix E. Results of each regeneration, GAC

## Process Overview

properties and a brief comparison of the effectiveness of virgin versus regenerated GAC for TOC removal are presented in Section 4 of this Chapter.

### FINAL PH CONTROL

Final pH control was begun in mid-February 1982 to compensate for the drop in pH caused by attempting breakpoint chlorination in the final disinfection process. During Phase IB, final pH control continued in order to reduce the corrosion potential of the finished water and the pH was maintained close to the 7.5 (+0.2) set point.

Sodium hydroxide, NaOH, was used for pH adjustment. The fifty percent NaOH solution was dripped into the GAC clearwell from a 55 gallon drum. Dilution water from GAC effluent was added at the caustic application point to aid in the dispersion of the chemical in the clearwell. Operators controlled the dose rate by measuring the pH of the process water at the end of the chlorine contact tank and adjusting NaOH feed accordingly. Doses ranged from approximately 15 mg/L during the period of breakpoint chlorination to 3 mg/L during normal operation. Caustic feed continued until the lime coagulation system was started.

### FINAL DISINFECTION

Chlorine was used as the final disinfectant for the first fifteen months of operation. Gaseous chlorine was fed from 68 kg (150 lb) cylinders into a stream of finished water via a remote injector arrangement. A standard chlorinator, capable of automatic control, was used to regulate the chlorine gas flow. The resulting chlorine solution was then introduced into the process flow in a 8 in. diameter pipe that delivered water from a GAC clearwell to the chlorine contact tank. The two stage contact tank had a serpentine-type baffling arrangement. Both stages were used. The detention time in the tank was sixty minutes at the plant flow rate. Hydraulic characterization of the tank, as described in Chapter 10 and in Appendix I, Section 10, indicated reasonably good plug flow with moderate longitudinal dispersion.

Manual samples for routine chlorine residual checks and bacteriological assays were taken from the effluent port of the contact tank. Operations personnel measured and recorded total and free chlorine residual every four hours regardless of whether the system was in an automatic or manual mode. In general, the automatic dose controller was used when ammonia levels were negligible and steady operation was easy to achieve.

During Phases IA and IB, several operating ranges of free chlorine residual were used for final disinfection. From startup to late June, the target range for free chlorine leaving the plant was between 1.0 and 1.5 mg/L. From late June through mid-December 1982, a free residual of between 2.0 and 2.5 was the goal. Average dosages and free and total chlorine residuals are shown in Table 7.1-1.

## Process Overview

Mechanically, the final disinfection process worked well and the only downtime was caused by process modifications. These included a change in the point of chlorine solution application, replacement of potable city water with EEWTP finished water for the chlorine solution system and some alterations to the chlorinator hardware.

### PLANT OPERATIONS AND MAINTENANCE STAFF

The EEWTP Operations and Maintenance staff consisted of a Plant Superintendent, four Shift Supervisors, five Operators, two Instrument Technicians, and one Mechanic. The plant was staffed on a twenty-four hour basis with a two-man crew consisting of a Shift Supervisor and Operator. Maintenance personnel were on duty during normal weekday working hours and were also available for emergency maintenance calls.

#### SHIFT SUPERVISORS

The Shift Supervisors had from two to thirty years previous experience supervising various aspects of wastewater treatment plant operations. Although most were unfamiliar with the unit processes used at the EEWTP, their experience and background made them quite adaptable and initial problems and training requirements were minimal.

#### OPERATORS

Each of the Operators had previous experience in the operation and/or maintenance of wastewater treatment plants. Background and experience varied considerably among the Operators and the diversity of talent aided in all aspects of plant operations.

#### MAINTENANCE STAFF

The experience of the three maintenance people totaled over sixty years in the fields of process equipment repair, instrument and electronic repair, and wastewater plant operations. The staff was qualified to handle most of the electrical and mechanical problems and modifications that arose during the operation of the plant.

## SECTION 2

### OVERALL PLANT PERFORMANCE

This section presents an overview of plant performance with respect to the water quality parameters monitored during Phase I of operation. The overall performance of the EEWTP is characterized in terms of the change in the levels of key parameters between the influent and the finished water. The key parameters examined in this section are grouped as follows: Physical/Aesthetic, Major Cations, Anions and Nutrients, Trace Metals, Radiological, Microbiological and Organics. For each group a tabular summary is provided indicating analytical results for parameters measured in the influent and finished water for Phases IA and IB. The tabular summaries present the number of samples analyzed (N); the number of samples above the method detection limit (No. Detected), which were used in the calculation of the geometric mean and spread factor; the percentage of overall removal through the plant based on geometric means for comparison; and the 95 percent confidence interval around the removal percentage. Parameters of special concern from either a water quality, health or operational standpoint are discussed in greater detail in Section 3, Fate of Contaminants.

#### PHYSICAL/AESTHETIC PARAMETERS

The physical/aesthetic group includes apparent color, free and total chlorine residual, methylene blue active substances (MBAS), odor, pH, corrosivity, taste, temperature, total suspended solids (TSS), turbidity, and asbestos.

Tables 7.2-1 and 7.2-2 present the results of physical/aesthetic analyses performed during Phase IA and IB, respectively. Temperature, influent and finished water pH and finished water free and total chlorine residual are shown as of function of time in Figure 7.2-1(a) through (c).

Table 7.2-3 presents the asbestos concentrations found in samples of the blended influent and finished water taken during Phases IA and IB. Asbestos fiber concentrations are given in terms of million fibers per liter, or MFL. Both chrysotile and amphibole fibers were counted. Average concentrations were computed by dividing the total number of fibers observed by the volume of sample which was effectively filtered and examined under the electron microscope.

When determining median and 90 percentile values, however, "Not Detected" samples were assumed to be less than the lowest reported concentration. This may not be strictly true, however, since detection limits vary with the filterability of the samples.

# Overall Plant Performance

TABLE 7.2-1  
OVERALL PROCESS PERFORMANCE  
PHYSICAL/AESTHETIC PARAMETERS  
PHASE 1A

	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Apparent Color	200	200	33.7	204	99	2.9	91	90.1	92.5
MDL = 3 Color Units									
MRAS	261	259	0.063	267	165	0.032	49	44.8	53.2
MDL = 0.03 mg/L									
Total Suspended Solids	203	202	13.35	208	12	NC <sup>b</sup>	>73 <sup>c</sup>		
MDL = 3.6 mg/L									
Turbidity	3917	3917	11.07	3914	3910	0.11	99	99.0	99.0
MDL = 0.05 NTU									

a. N = Number of Samples Analyzed

b. NC = Not Calculated (Less Than 15% Above MDL)

c. Overall Removal Calculated Using MDL As Effluent Concentration

## Overall Plant Performance

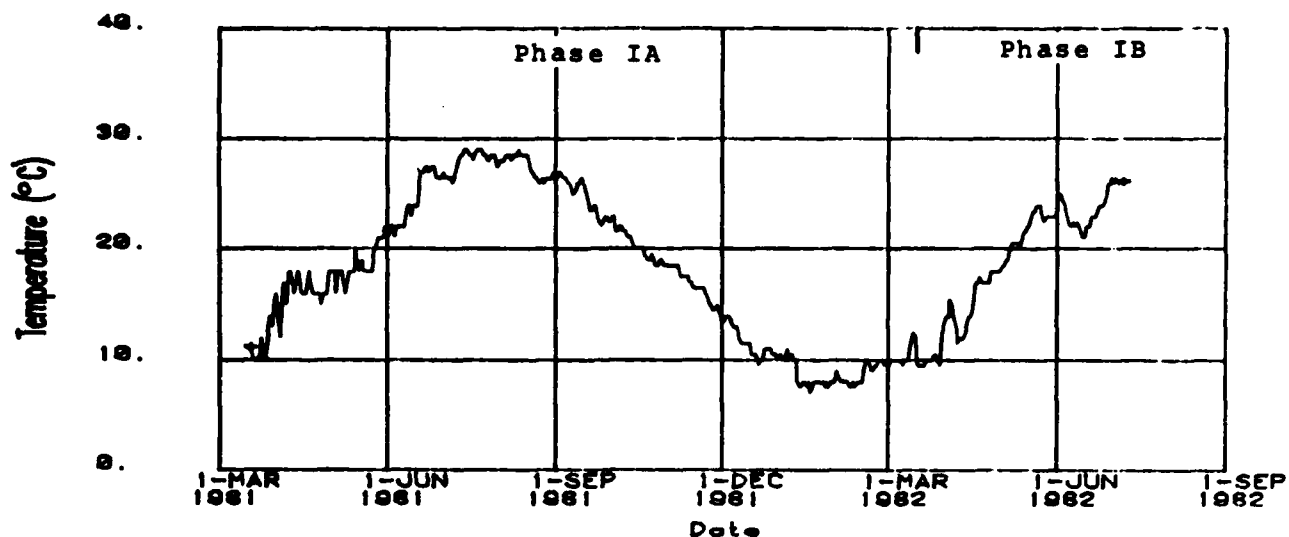
TABLE 7.2-2  
OVERALL PROCESS PERFORMANCE  
PHYSICAL/AESTHETIC PARAMETERS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	Detected	Geometric Mean	N	Detected	Geometric Mean		Lower	Upper
Apparent Color									
MDL = 3 Color Units	13	13	44.9	14	12	4.9	89	85.9	91.1
MBAS									
MDL = 0.03 mg/L	2	2	0.049	4	4	0.035	29	7.0	52.3
Total Suspended Solids									
MDL = 3.6 mg/L	11	11	19.79	14	0	NC <sup>b</sup>	>81 <sup>c</sup>		
Turbidity									
MDL = 0.05 NTU	662	662	15.32	668	668	0.10	99	99.3	99.4

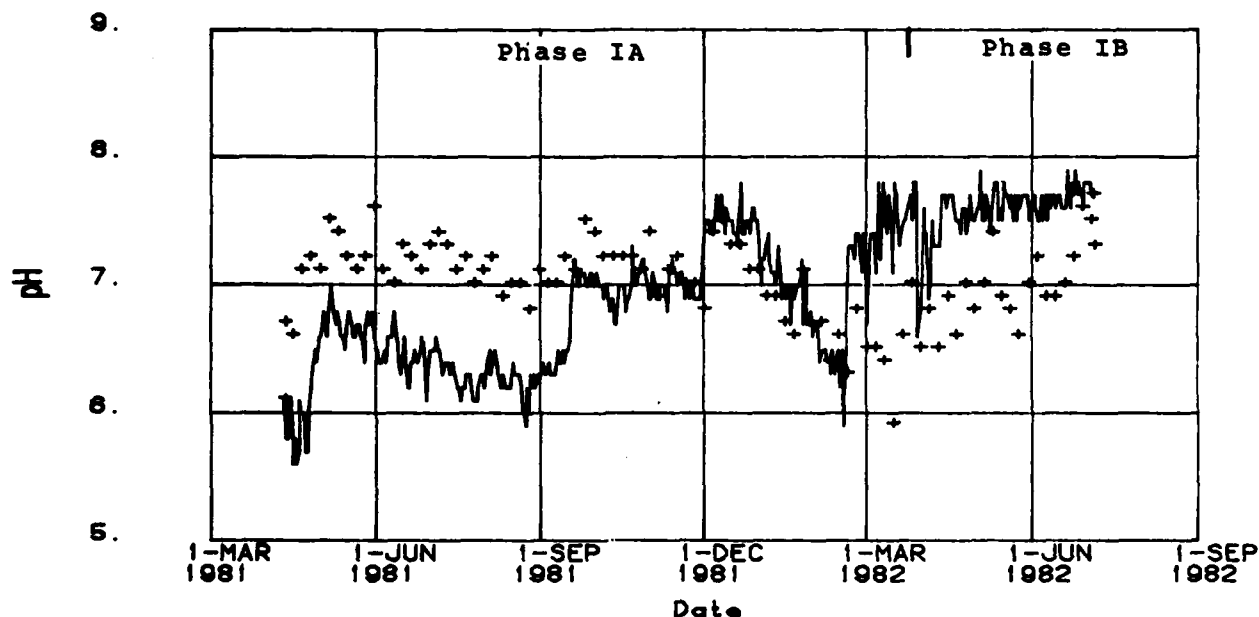
a. N = Number of Samples Analyzed

b. NC = Not Calculated (less than 15 percent above MDL)

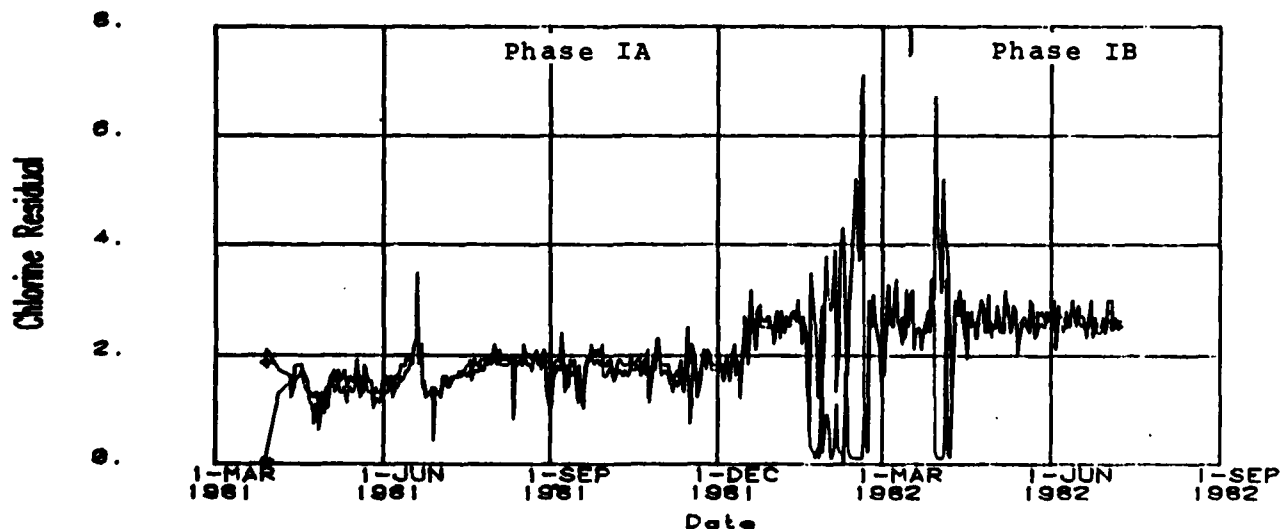
c. Overall Removal Calculated Using MDL as Effluent Concentration



(a) Finished Water Temperature



(b) Influent and Finished Water pH



(c) Finished Water Free and Total Chlorine Residual

### PHYSICAL / AESTHETIC PARAMETERS (PHASES IA AND IB)

FIGURE 7. 2-1



## Overall Plant Performance

In both Phases IA and IB, the chrysotile concentration was reduced by greater than 99 percent between the blend tank effluent and finished water clearwell.

TABLE 7.2-3

### ASBESTOS CONCENTRATIONS PHASES IA AND IB

	Blended Influent Concentration, MFL <sup>1</sup>		Finished Water Concentration, MFL	
	<u>Chrysotile</u>	<u>Amphibole</u>	<u>Chrysotile</u>	<u>Amphibole</u>
Phase IA				
N <sup>2</sup>	49	8	48	48
Average	6.007	ND <sup>3</sup>	0.025	ND
Median	2.926	NC <sup>4</sup>	ND	ND
90 Percentile	13.960	NC	ND	ND
Phase IB				
N	13	15	16	16
Average	5.880	0.698	0.017	ND
Median	4.560	NC	ND	ND
90 Percentile	17.955	NC	ND	ND

1. MFL = Million Fibers Per Liter.

2. N = Number of samples analyzed.

3. ND = Not detected.

4. NC = Not calculated.

5. Only one sample was analyzed for Amphibole fibers in Phase IB blended influent.

### MAJOR CATIONS, ANIONS AND NUTRIENTS

This group includes the parameters listed in Tables 7.2-4 and 7.2-5. The minerals listed in these tables cover operating periods IA and IB, respectively. Iodide does not appear in Table 7.2-5, however, because it was dropped from the testing schedule in December 1981 under the revised sampling program.

Although many of the parameters listed in this category were unaffected by the treatment processes used during Phases IA and IB, overall removal percentages with confidence intervals are provided to indicate the effect of the treatment processes on these parameters. Concentration changes in several of the parameters listed reflect the addition of various process chemicals. For example, alum increased the sulfate content, and correspondingly, the electroconductivity and TDS of the finished water, while consuming alkalinity. Lime, on the other hand, increased alkalinity and the calcium content of the finished water. Other chemicals used during operation that increased the general mineral content of the finished water to some degree were chlorine (chlorides), sodium hydroxide (sodium), and potassium permanganate (potassium). The parameters in this group which were consistently removed by at least fifty percent in both Phases IA and IB included bromide, cyanide and ammonia nitrogen.

# Overall Plant Performance

TABLE 7.2-4  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE 1A

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	Na	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Alkalinity-CaCO <sub>3</sub> MDL = 2.7 mg/L	274	274	58.14	282	282	37.69	35	30.6	39.4
Bromide MDL = 0.003 mg/L	272	265	0.0574	282	115	0.0022	96	94.2	97.0
Calcium MDL = 0.2 mg/L	276	276	45.62	281	281	47.18	-3	-8.2	1.1
Chloride MDL = 0.1 mg/L	275	275	42.43	284	284	46.37	-9	-14.0	-4.8
Cyanide, Total MDL = 0.0005 mg/L	283	180	0.0064	283	75	0.0024	60	46.5	71.0
Electroconductivity MDL = 0.1 $\mu$ mho/cm	2107	2107	446	201	201	465	-4	-6.6	1.9
Fluoride MDL = 0.1 mg/L	273	270	0.49	283	277	0.30	39	35.1	42.0
Hardness-CaCO <sub>3</sub> MDL = 1.0 mg/L	276	276	147.2	280	280	150.7	-2	-7.0	2.0
Iodide MDL = 0.002 mg/L	246	237	0.0048	252	218	0.0032	33	26.9	39.0
Magnesium MDL = 0.1 mg/L	276	276	8.01	280	280	7.88	2	-3.0	6.0
Nitrogen: Ammonia MDL = 0.02 mg/L -N	277	251	0.128	285	65	0.002	98	96.9	99.2
Nitrogen: Nitrite+Nitrate MDL = 0.02 mg/L -N	276	276	6.9	285	284	6.9	0	-7.0	7.3
Nitrogen: Total Kjeldahl MDL = 0.02 mg/L -N	269	253	0.82	30	21	0.29	65	51.7	74.0
Orthophosphate MDL = 0.01 mg/L -P	275	275	0.347	285	27	NC <sup>b</sup>	>34 <sup>c</sup>	Not Calculated	

# Overall Plant Performance

TABLE 7.2-4 (Continued)  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE 1A

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup> Detected	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Potassium MDL = 0.3 mg/L	276	276	5.92	281	280	5.98	-1	-5.1	2.9
Silica MDL = 0.2 mg/L	276	276	6.49	283	283	5.43	16	11.1	21.2
Sodium MDL = 0.1 mg/L	276	276	29.10	281	281	28.73	1	-3.7	6.0
Sulfate MDL = 0.6 mg/L	276	276	65.76	284	284	91.10	-39	-43.2	-34.0
Total Dissolved Solids MDL = 10.0 mg/L	183	183	264.3	189	189	273.7	-4	-7.5	0.2

a. N = Number of Samples Analyzed.

b. NC = Not Calculated (Less than 15% above MDL).

c. Overall Removal Calculated Using MDL as Effluent Concentration.

## Overall Plant Performance

TABLE 7.2-5  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean			Lower	Upper
Alkalinity-CaCO <sub>3</sub> MDL = 2.7 mg/L	23	54.87	28	28	60.65		-11	26.7	3.5
Bromide MDL = 0.003 mg/L	23	0.0651	28	5	0.0004		99	94.6	99.9
Calcium MDL = 0.2 mg/L	27	42.02	32	32	49.16		-17	-25.6	-9.0
Chloride MDL = 0.1 mg/L	23	45.45	28	28	39.68		13	-6.2	28.0
Cyanide-Total MDL = 0.005 mg/L	26	0.0044	32	0	NC <sup>b</sup>		NC	NC	NC
Electroconductivity MDL = 0.1 umho/cm	683	365.1	28	28	427.7		-17	-27.9	-7.3
Fluoride MDL = 0.1 mg/L	23	0.44	28	25	0.23		48	36.6	56.9
Hardness-CaCO <sub>3</sub> MDL = 1.0 mg/L	27	134	32	32	150		-12	-20.0	-4.0
Magnesium MDL = 0.1 mg/L	27	7.05	33	33	6.61		6	-1.4	12.5
Nitrogen: Ammonia MDL = 0.002 mg/L -N	23	0.127	28	9	0.008		94	75.9	98.0
Nitrogen: Nitrite+Nitrate MDL = 0.02 mg/L -N	23	6.66	28	28	5.09		24	1.8	40.0
Nitrogen: Total Kjeldahl MDL = 0.2 mg/L -N	23	0.83	28	5	0.05		94	76.9	98.0
Orthophosphate MDL = 0.01 mg/L -P	23	0.199	28	4	NC		>95 <sup>c</sup>	NC	NC
Potassium MDL = 0.3 mg/L	27	5.15	33	33	4.46		14	2.2	24.0

## Overall Plant Performance

TABLE 7.2-5 (Continued)  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Silica									
MDL = 0.2 mg/L	23	23	7.67	28	28	5.97	22	9.0	33.0
Sodium									
MDL = 0.1 mg/L	27	27	22.51	33	33	21.97	2	-11.9	14.0
Sulfate									
MDL = 0.6 mg/L	23	23	38.24	28	28	59.52	-56	-67.6	-44.0
Total Dissolved Solids									
MDL = 10.0 mg/L	22	22	207.8	28	28	231.1	-11	-21.0	-2

a. N = Number of Samples Analyzed.

b. NC = Not Calculated (less than 15% above MDL).

c. Overall Removal Calculated Using MDL as Finished Water Concentration.

## Overall Plant Performance

The parameters within the anion, cation and nutrient grouping that are in high enough concentrations to be of special concern because of health or operational issues are ammonia, nitrate and sodium. These parameters are discussed in Section 3.

### TRACE METALS PARAMETERS

Trace metals removal data for Phase IA are shown in Table 7.2-6. Table 7.2-7 contains similar data for the Phase IB period. In general, the finished water concentrations of metals included in the National Interim Primary Drinking Water Regulations (NIPDWR) were well below the maximum levels allowed. However, manganese which is included in the secondary regulations often exceed its MCL of 0.05 mg/L during Phase IA.

Antimony, mercury, selenium and zinc increased in concentration through the plant during Phase IA. Evidence suggests that this was caused by the dissolution of metals in contact with the process flow during the first several months of operation when the product water was corrosive. This trend was not seen in Phase IB when plant water was neutral with respect to corrosivity as measured by the Langlier Index. The trace metal portion of Section 3 of this chapter addresses the problem in greater detail and also discusses metals of special interest or concern.

### RADIOLOGICAL PARAMETERS

The results of radiological testing, performed weekly on influent and finished waters for Phases IA and IB, are presented in Tables 7.2-8 and 7.2-9. Gross alpha activity was below the MCL of 15 pCi/L and also met the 5 pCi/L test which is a criterion for additional radionuclide testing. A thorough explanation of radiological testing protocols and monitoring requirements is presented in Chapter 9 of this report. The 95 percent confidence intervals on removal of radiological parameters is indicative of the large uncertainty in observed results and firm conclusions cannot be drawn. In any event, the observed levels of radioactivity in the influents and finished water were quite low and not of health concern; see Chapter 9.

## Overall Plant Performance

TABLE 7.2-6  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE IA

Parameter	Blended Influent			Finished Water			Overall Removal	95% Confidence Interval	
	N <sup>a</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Aluminum									
MDL = 0.003 mg/L	273	266	0.3166	279	226	0.0187	94	92.5	95.4
Antimony									
MDL = 0.003 mg/L	273	90	0.00014	278	133	0.00025	-79	-159.3	-23.6
Arsenic									
MDL = 0.0002 mg/L	274	244	0.00065	279	148	0.00021	68	57.4	75.5
Barium									
MDL = 0.002 mg/L	271	264	0.0291	276	275	0.0215	26	18.7	32.8
Beryllium									
MDL = 0.0008 mg/L	272	0	NC <sup>b</sup>	278	0	NC	NC	NC	NC
Boron									
MDL = 0.004 mg/L	274	272	0.0393	279	270	0.03349	15	2.5	25.5
Cadmium									
MDL = 0.0008 mg/L	250	54	0.00041	253	33	NC	NC	NC	NC
Chromium									
MDL = 0.0008 mg/L	250	78	0.0022	253	6	NC	>64 <sup>c</sup>	NC	NC
Cobalt									
MDL = 0.0001 mg/L	22	22	0.0037	25	20	0.00035	91	83	95
Copper									
MDL = 0.008 mg/L	251	240	0.00609	253	174	0.00157	74	68.6	78.8
Iron									
MDL = 0.003 mg/L	272	271	1.0915	279	240	0.248	98	97.2	98.2
Lead									
MDL = .0003 mg/L	273	246	0.00158	279	153	0.00033	79	73.2	83.7
Lithium									
MDL = 0.001 mg/L	251	249	0.00494	251	242	0.00404	18	10.1	25.6
Manganese									
MDL = 0.001 mg/L	274	274	0.16456	279	279	0.03051	81	78.5	84.0
Mercury									
MDL = 0.00027 mg/L	267	64	0.00009	279	103	0.0002	-122	-234.5	-47.6

## Overall Plant Performance

TABLE 7.2-6 (Continued)  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE IA

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Molybdenum MDL = 0.002 mg/L	271	12	NC	276	24	NC	NC	NC	NC
Nickel MDL = 0.001 mg/L	268	253	0.00405	276	218	0.00239	41	32.5	48.4
Selenium MDL = 0.0002 mg/L	274	176	0.00039	279	194	0.00051	-31	80.1	5.0
Silver MDL = 0.0008 mg/L	251	37	NC	253	10	NC	NC	NC	NC
Thallium MDL = 0.0009 mg/L	273	2	NC	278	6	NC	NC	NC	NC
Tin MDL = 0.004 mg/L	270	79	0.00248	275	58	0.00128	48	22.1	65.8
Titanium MDL = 0.002 mg/L	271	233	0.0075	277	5	NC	>73 <sup>c</sup>	NC	NC
Vanadium MDL = 0.002 mg/L	272	199	0.00333	277	156	0.00249	25	6.0	40.5
Zinc MDL = 0.002 mg/L	250	250	0.02085	252	252	0.05913	-184	-208.2	-160.7

a. N = Number of Samples Analyzed.

b. NC = Not Calculated.

c. Overall Removal Calculated Using MDL as Effluent Concentration.



TABLE 7.2-7  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal	95% Confidence Interval		
	N <sub>a</sub>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		%	Lower	Upper
Aluminum										
MDL = 0.003 mg/L	27	27	.6214	32	32	0.1601	74	59.5	83.6	
Arsenic										
MDL = 0.0002 mg/L	27	27	0.0011	32	28	0.0005	55	37.5	66.9	
Barium										
MDL = 0.002 mg/L	27	27	0.0383	32	32	0.0245	36	22.0	47.1	
Boron										
MDL = 0.004 mg/L	27	27	0.0456	32	32	0.0437	4	20.9	24.0	
Cadmium (Furnace AAS)										
MDL = 0.0002 mg/L	27	16	0.0002	32	6	0.00004	83	7.4	96.7	
Chromium (Furnace AAS)										
MDL = 0.0002 mg/L	27	27	0.0056	32	29	0.0009	84	76.4	89.1	
Copper (Flame AAS)										
MDL = 0.0012 mg/L	27	26	0.0083	32	21	0.0013	84	79.0	88.3	
Iron										
MDL = 0.003 mg/L	27	27	1.5673	32	28	0.0167	99	98.2	99.4	
Lead										
MDL = 0.0003 mg/L	27	26	0.002	32	7	0.0001	95	88.7	97.8	
Lithium (Flame AAS)										
MDL = 0.0004 mg/L	27	27	0.0051	32	32	0.0045	12	-16.5	33.1	
Manganese										
MDL = 0.001 mg/L	27	27	0.2365	32	27	0.0045	98	96.7	98.9	
Mercury										
MDL = 0.00027 mg/L	27	2	NC <sup>b</sup>	32	11	0.0002	NC	NC	NC	
Nickel										
MDL = 0.001 mg/L	27	26	0.0052	32	18	0.0014	73	43.2	87.2	
Selenium										
MDL = 0.0002 mg/L	27	4	NC	32	7	0.0000	NC	NC	NC	

Overall Plant Performance

# Overall Plant Performance

TABLE 7.2-7 (Continued)  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Silver (Furnace AAS) MDL = 0.0002 mg/L	27	20	0.0004	32	2	NC	NC	NC	NC
Tin MDL = 0.004 mg/L	27	26	0.0198	32	1	NC	NC	NC	NC
Vanadium MDL = 0.002 mg/L	27	22	0.0041	32	5	0.0008	80	55.3	91.5
Zinc MDL = 0.0012 mg/L	27	27	0.0293	32	32	0.0092	67	53.8	78.7
Titanium MDL = 0.002 mg/L	27	26	0.0194	32	1	NC	NC	NC	NC

a. N = Number of Samples Analyzed.  
b. NC = Not Calculated.

# Overall Plant Performance

TABLE 7.2-8  
OVERALL PROCESS PERFORMANCE  
RADIOLOGICAL PARAMETERS  
PHASE 1A

<u>Parameter</u>	<u>Blended Influent</u>			<u>Finished Water</u>			<u>Overall Removal</u>	<u>95% Confidence Interval</u>	
	<u>N</u> <sup>1</sup>	<u>Detected</u>	<u>Geometric Mean</u>	<u>N</u>	<u>Detected</u>	<u>Geometric Mean</u>		<u>Lower</u>	<u>Upper</u>
Gross Alpha MDL = .1 pCi/L	46	32	.25	45	22	.1	62	7.1	82.8
Gross Beta MDL = .1 pCi/L	47	42	3.23	46	46	5.93	-83	-242	1.4
Strontium MDL = .2 pCi/L	16	9	0.05	11	7	.55	-1000	-15,545	22.7

1. N = Number of Samples Analyzed

# Overall Plant Performance

TABLE 7.2-9  
OVERALL PROCESS PERFORMANCE  
RADIOLOGICAL PARAMETERS  
PHASE IB

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Gross Alpha MDL = .1 pCi/L	7	5	.37	7	2	.03	92	-629	99.9
Gross Beta MDL = .1 pCi/L	7	7	6.8	7	7	5.02	26	9.8	39.6

1. N = Number of Samples Analyzed

## Overall Plant Performance

### MICROBIOLOGICAL PARAMETERS

The following microbiological parameters were monitored in the EEWTP blended influent and finished water during Phases IA and IB of plant operations: total coliforms, standard plate count (SPC) bacteria, Salmonella bacteria, enteric viruses, parasites and endotoxin. Fecal coliforms in the blend were not enumerated during Phase IA testing. Weekly samples from the blend tank were analyzed in Phase IB, however. Indicators of microbiological quality such as the coliforms and SPC were monitored more frequently than the specialized pathogens. Generally more samples were analyzed from the finished water than the blended influent for all microbiological parameters.

#### TOTAL COLIFORMS, FECAL COLIFORMS AND STANDARD PLATE COUNT

Tables 7.2-10 and 7.2-11 show overall plant performance in terms of percent removal and log reduction ( $\log_{10}$  in -  $\log_{10}$  out) of the three major indicators of microbiological quality during both phases of operation. Greater than 6.0 logs of total coliforms, 5.4 logs of fecal coliforms and 4.1 logs of SPC bacteria were removed from the EEWTP blend. Although high coliform removals were achieved, the levels of coliform in the finished water often exceeded values observed in the local plants, as discussed in Chapter 9. It must be stressed, however, that the coliform levels never exceeded the NIPDWR MCL for coliform. Because of the importance of microbiological quality for determining the acceptability of the finished water for human consumption, this is discussed in greater detail in Section 3.

#### SALMONELLA

Salmonella organisms entering the EEWTP were removed to below the assay detection limit as shown in Table 7.2-12. Salmonella were not detected in any of the ten finished water samples assayed in Phase IA or the three in Phase IB.

#### ENTERIC VIRUSES

Blue Plains nitrified effluent and the Potomac River estuary each contributed viruses to the EEWTP blended influent. This is shown in Table 7.2-13 for Phase IA monitoring. These two influent sites were not monitored during Phase IB with the exception of two Potomac estuary samples collected after 16 March 1982. Both samples were negative. All eleven finished water samples analyzed during Phase IA were also negative.

The results of thirteen influent and fifteen finished water samples, concentrated and assayed for the presence of enteric viruses during Phase IB, are presented in Table 7.2-14.

# Overall Plant Performance

TABLE 7.2-10  
PROCESS PERFORMANCE - MICROBIOLOGICAL PARAMETERS  
PHASE IA

	<u>Blended Influent</u>	<u>Finished Water</u>	<u>% Removal</u>	<u>Over-All Log Removal</u>
<u>Total Coliforms (MPN/100 ml)</u>				
Number of Samples	15 <sup>c</sup>	255		
No. Quantified	15	181		
Geometric Mean	$6.4 \times 10^4$	$3.1 \times 10^{-2}$	99.99995	6.3
Median	$5.4 \times 10^4$	$2 \times 10^{-2}$	99.99996	6.4
90% Value	$3.5 \times 10^5$	$1.4 \times 10^{-1}$	99.99996	6.4
<u>Fecal Coliforms (MPN/100 ml)</u>				
Number of Samples	NA <sup>a</sup>	187		
No. Quantified		25		
Geometric Mean		NC <sup>b</sup>	NC	NC
Median		$<1.8 \times 10^{-2}$	NC	NC
90% Value		$2 \times 10^{-2}$	NC	NC
<u>Standard Plate Count (Colonies/ml)</u>				
Number of Samples	14 <sup>c</sup>	258		
No. Quantified	14	58		
Geometric Mean	$2.9 \times 10^4$	$2 \times 10^{-1}$	99.9993	5.2
Median	$3.2 \times 10^4$	$<1.0$	$>99.9969$	$>4.5$
90% Value	$8 \times 10^4$	2.0	99.9975	3.6
<u>Salmonella (MPN/100 ml)</u>				
Number of Samples	4	10		
No. Quantified	4	0		
Geometric Mean	$6.4 \times 10^{-1}$	NC	NC	NC
Median	$5.1 \times 10^{-1}$	$<2.2 \times 10^{-2}$	$>96$	$>1.4$
90% Value	1.6	$<2.2 \times 10^{-2}$	$>98$	$>1.9$

a. NA = Not analyzed during Phase IA.

b. NC = Not calculated.

c. Weekly analysis began at these sites on 1 December 1981.

# Overall Plant Performance

TABLE 7.2-11  
PROCESS PERFORMANCE - MICROBIOLOGICAL PARAMETERS  
PHASE IB

	Blended Influent	Finished Water	% Removal	Over-All Log Removal
<u>Total Coliforms (MPN/100 ml)</u>				
Number of Samples	13	68		
No. Quantified	13	19		
Geometric Mean	$2.2 \times 10^4$	$8 \times 10^{-3}$	99.99996	6.4
Median	$2.2 \times 10^4$	$< 1.8 \times 10^{-2}$	>99.99991	>6.1
90% Value	$3.5 \times 10^4$	$2 \times 10^{-2}$	99.99994	6.2
<u>Fecal Coliforms (MPN/100 ml)</u>				
Number of Samples	13	71		
No. Quantified	13	3		
Geometric Mean	$4.9 \times 10^3$	NC	NC	NC
Median	$4.9 \times 10^3$	$< 1.8 \times 10^{-2}$	>99.9996	>5.4
90% Value	$1.1 \times 10^4$	$< 1.8 \times 10^{-2}$	>99.9998	>5.8
<u>Standard Plate Count (Colonies/ml)</u>				
Number of Samples	13	75		
No. Quantified	13	16		
Geometric Mean	$1.6 \times 10^4$	$4 \times 10^{-1}$	99.9975	4.6
Median	$1.4 \times 10^4$	<1	>99.9928	>4.1
90% Value	$3.8 \times 10^4$	2.0	99.9947	4.3
<u>Salmonella (MPN/100 ml)</u>				
Number of Samples	3	3		
No. Quantified	2	0		
Geometric Mean	$> 1.6 \times 10^0$	NC		NC
Median	$2.2 \times 10^{-1}$	$< 2.2 \times 10^{-2}$	>90	>1.0
90% Value	$2.2 \times 10^{-1}$	$< 2.2 \times 10^{-2}$	>90	>1.0

TABLE 7.2-12  
OVERALL SALMONELLA REMOVAL  
PHASES IA AND IB

	Blend		Finished Water		% Removal	
Salmonella (MPN/100 ml)	IA	IB	IA	IB	IA	IB
N <sup>1</sup>	4	3	10	3		
Geometric Mean	0.64	NC <sup>2</sup>	NC	NC	—	—
Median	0.51	0.22	<0.02	<0.02	>96.1	>90.9
90% Value	1.6	0.22	<0.02	<0.02	>98.8	>90.9

1. Number of samples analyzed.

2. NC = Not Calculated.

# Overall Plant Performance

TABLE 7.2-13  
ENTERIC VIRUSES IN PHASE IA  
EEWTP INFLUENTS AND FINISHED WATER

	<u>Blue Plains Effluent</u>	<u>Potomac River Estuary</u>	<u>EEWTP Blended Influent</u>	<u>EEWTP Finished Water</u>
No. of Samples	10	11	4	11
Total Volume	4,062	2,195	1,044	10,305
Concentrated (gallons)				
Equivalent Volume Applied	2,031	1,098	5,222	5,153
To Cells (gallons) <sup>1</sup>				
No. of Positive Samples <sup>2</sup>	4	6	1	0

1. Approximately one-half of the virus concentrate was inoculated onto cell monolayers.
2. A sample was positive if it elicited cytopathic effects in at least one of the cell lines tested.

TABLE 7.2-14  
ENTERIC VIRUSES IN PHASE IB  
EEWTP BLENDED INFLUENT AND FINISHED WATER

	<u>EEWTP Blended Influent</u>	<u>EEWTP Finished Water</u>
No. of Samples	13	15
Total Volume Concentrated (gallons)	2,362	15,139
Equivalent Volume Applied to Cells (gallons)	1,181	7,570
No. of Positive Samples	6	---



## Overall Plant Performance

Six of the thirteen blended influent samples from this period were positive in at least one of the cell lines tested. No viruses were detected in any of the finished water samples for this period.

Quantitative enteric virus results for each influent source and the blended influent during Phase IA are shown in Table 7.2-15. Positive samples in the nitrified effluent ranged between >0.02 and 0.168 MPNCU/gal (most probable number cytopathic units/gallon). The estuary concentration range for positively identified viruses was between 0.082 and 0.269 MPNCU/gal. Viruses isolated from positive tube cultures in Phase IA were identified, as shown in Table 7.2-16. The three major virus groups identified were Coxsackievirus, Echovirus and Poliovirus.

The results of the EEWTP blend assays in Phase IB are given in Table 7.2-17. Positive samples ranged from 0.008 to 0.266 MPNCU/gal.

Viruses identified from the blended influent during Phase IB constituted the same major groups identified from the nitrified effluent, the Potomac River and the blend tank observed in Phase IA. These identifications are shown in Table 7.2-18.

### PARASITES

Five EEWTP blended influent samples were concentrated and assayed for parasites during Phase IA and IB. A total of 765 gallons were filtered and 627 equivalent gallons were microscopically examined in the concentrated material. No parasites were detected in the blend samples or in the nineteen finished water samples assayed during both phases. Approximately 13,000 gallons of EEWTP finished water were filtered and 2,500 equivalent gallons were examined microscopically.

### ENDOTOXIN

Only one blend sample was analyzed during Phase IA. The endotoxin concentration was 62.4 ng/L. Nine finished water samples gave a geometric mean, median and 90 percentile of 2.9, 5.0, and 12.5 ng/L, respectively. One finished water sample was analyzed in Phase IB at a concentration of 2.5 ng/L.

# Overall Plant Performance

TABLE 7.2-15  
ENTERIC VIRUSES IN PHASE IA EEWTP INFLUENTS

<u>Sampling Location</u>	<u>Sampling Date</u>	<u>Volume Filtered (Gallons)</u>	<u>Cell Line</u>	<u>Lower Detection Limit (MPNCU/Gallon)</u>	<u>Concentration (MPNCU/Gallon)</u>
Potomac River Estuary	22 April 1981	105.0	BGM	.030	N.D.
			RD	.030	N.D.
	28 May 1981	217.0	BGM	.016	N.D.
			RD	.016	N.D.
	12 July 1981	1000.0	BGM	.003	N.D.
			RD	.003	N.D.
	15 July 1981	150.0	BGM	.006	N.D.
			MA104	.006	N.D.
	26 August 1981	146.0	BGM	.092	N.D.
			MA104	.092	.092
	6 October 1981	123.0	BGM	.122	.122
			MA104	.122	.122
	6 November 1981	61.0	BGM	.252	N.D.
			MA104	.252	N.D.
	17 December 1981	127.0	BGM	.082	.082
			MA104	.082	N.D.
	18 January 1982	65.0	BGM	.152	>.152
			MA104	.122	>.122
	18 February 1982	67.0	BGM	.076	<.170
			MA104	.076	.269
	12 March 1982	114.0	BGM	.052	>.177
			MA104	.052	.117

# Overall Plant Performance

TABLE 7.2-15 (Continued)  
ENTERIC VIRUSES IN PHASE I A EEWTP INFLUENTS

<u>Sampling Location</u>	<u>Sampling Date</u>	<u>Volume Filtered (Gallons)</u>	<u>Cell Line</u>	<u>Lower Detection Limit (MPNCU/Gallon)</u>	<u>Concentration (MPNCU/Gallon)</u>
Blue Plains Effluent	22 April 1981	93.0	BGM	.043	N.D.
			RD	.043	N.D.
	28 May 1981	448.0	BGM	.010	N.D.
			RD	.010	N.D.
	1 July 1981	1000.0	BGM	.002	N.D.
			RD	.002	N.D.
	15 July 1981	683.0	BGM	.004	N.D.
			MA104	.004	N.D.
	26 August 1981	364.0	BGM	.042	N.D.
			MA104	.042	N.D.
	6 October 1981	400.0	BGM	.020	N.D.
			MA104	.040	>.020
	10 November 1981	250.0	BGM	.066	>.040
			MA104	.072	>.066
	18 December 1981	431.0	BGM	.022	>.072
			MA104	.022	N.D.
EEWTP Blended Influent	20 January 1982	107.0	BGM	.168	N.D.
			MA104	.140	>.168
	19 February 1982	286.0	BGM	.013	>.140
			MA104	.013	>.042
	17 December 1981	281.0	BGM	.040	N.D.
			MA104	.040	N.D.
	21 January 1982	300.0	BGM	.016	N.D.
			MA104	.009	N.D.
	19 February 1982	333.0	BGM	.016	N.D.
			MA104	.016	N.D.
	13 March 1982	130.0	BGM	.056	>.122
			MA104	.056	>.097

# Overall Plant Performance

TABLE 7.2-16  
ENTERIC VIRUSES IDENTIFIED IN PHASE IA  
IN EEWTP INFLUENTS

<u>Virus</u>	<u>Nitrified Effluent</u>	<u>Potomac Estuary</u>
Coxsackievirus B3	—	2
Coxsackievirus B4	4	1
Echovirus Type 7	1	—
Echovirus Type 9	1	—
Echovirus Type 11	1	1
Echovirus Type 15	—	1
Echovirus Type 21	—	1
Echovirus Type 27	1	1
Poliovirus Type 1	---	1
Poliovirus Type 2	2	1
Poliovirus Type 3	1	—
Unidentifiable	1	3

# Overall Plant Performance

TABLE 7.2-17  
ENTERIC VIRUSES IN PHASE IB EEWTP BLEND

<u>Sampling Location</u>	<u>Sampling Date</u>	<u>Volume Filtered (Gallons)</u>	<u>Cell Line</u>	<u>Lower Detection Limit (MPNCU/Gallon)</u>	<u>Concentration (MPNCU/Gallon)</u>
EEWTP Blended Influent	10 April 1982	80.0	BGM	.020	N.D.
			MA104	.040	N.D.
	12 April 1982	87.0	BGM	.050	N.D.
			MA104	.050	N.D.
	13 April 1982	106.0	BGM	.040	N.D.
			MA104	.040	N.D.
	16 April 1982	213.0	BGM	.020	N.D.
			MA104	.020	N.D.
	7 May 1982	119.0	BGM	.022	N.D.
			MA104	.022	N.D.
	14 May 1982	344.0	BGM	.008	N.D.
			MA104	.008	N.D.
	28 May 1982	325.0	BGM	.008	N.D.
			MA104	.008	N.D.
	7 June 1982	173.0	BGM	.013	.148
			MA104	.013	.013
	8 June 1982	321.0	BGM	.007	N.D.
			MA104	.007	N.D.
	11 June 1982	296.0	BGM	.008	.116
			MA104	.008	>.166
	18 June 1982	76.0	BGM	.032	.112
			MA104	.032	.070
	25 June 1982	143.0	BGM	.017	.266
			MA104	.017	.199
	2 July 1982	183.0	BGM	.011	N.D.
			MA104	.011	.038

## Overall Plant Performance

TABLE 7.2-18  
ENTERIC VIRUSES IDENTIFIED IN PHASE IB EEWTP BLEND

<u>Virus</u>	<u>Number of Isolates Identified</u>
Coxsackievirus B2	2
Coxsackievirus B4	1
Poliovirus Type 3	2
Echovirus Type 5	1
Echovirus Type 11	1
Echovirus Type 12	1
Echovirus Type 33	1
Unidentifiable <sup>1</sup>	5

1. These were confirmed virus isolates which could not be identified with the Lim Benyesh-Meinick antisera pools.

### ORGANIC PARAMETERS

This section discusses the overall removal of organic parameters during the alum phases of operation. Overall removal is based on a comparison of geometric mean concentrations in the GAC effluent to those found in the blended influent. The influence of individual unit processes on the removal and/or formation of organic compounds is discussed in more detail in Sections 3 and 4.

### SURROGATE PARAMETERS

The overall removals of the surrogate organic parameters, TOC and TOX are listed in Table 7.2-19 for Phases IA and IB. The data show that the levels of these surrogate parameters were above the MDL in nearly all samples in both the blended influent and GAC effluent during both phases. The geometric mean concentration of TOC in the blended influent was higher in Phase IB, while the geometric mean concentration of influent TOX was higher during Phase IA. The overall removal during these phases was greater than fifty percent for both parameters. Higher overall percent removals for both parameters were observed during Phase IB, when ozone was used as the intermediate disinfectant. The main reason for increased TOX removal in Phase IB was the reduction in TOX formation by eliminating intermediate chlorination.

### PRIMARY ORGANIC COMPOUNDS

Figures 7.2-2 and 7.2-3 illustrate the overall removal of primary organic compounds detected in more than fifteen percent of the samples for Phase IA and IB, respectively. The primary organic compounds consist of a total of 151 compounds, not including the THMs. The pesticide/PCB and base/neutral fractions were not included, because no compounds were detected in either of

## Overall Plant Performance

TABLE 7.2-19  
OVERALL PLANT PERFORMANCE  
REMOVAL OF SURROGATE ORGANIC PARAMETERS  
PHASE IA AND IB

Parameter <sup>1</sup>	Blended Influent			GAC Effluent			Overall Removal %	95% Confidence Interval	
	N <sup>2</sup>	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Phase IA									
TOC	293	293	4.50	307	307	1.41	68.7	66.5	70.7
MDL=0.06 mg/L-C									
TOX	298	298	84.98	309	304	42.88	49.5	46.0	52.8
MDL=3.9 µg/L-Cl									
Phase IB									
TOC	51	51	4.63	59	59	1.16	75.0	71.6	77.4
MDL=0.06 mg/L-C									
TOX	51	51	76.70	59	59	17.06	77.8	74.5	80.6
MDL=3.9 µg/L-Cl									

1. All samples were 24-hour composites.

2. N = Number of samples analyzed.

## Overall Plant Performance

these groups. No clear trends in overall removals of these compounds can be seen from these two figures.

Figures 7.2-2 and 7.2-3 point out the small number of primary organic compounds detected in either the blended influent or GAC effluent during these two phases of EEWTP operation. The two sections below highlight these characteristics of the primary organic compounds routinely detected.

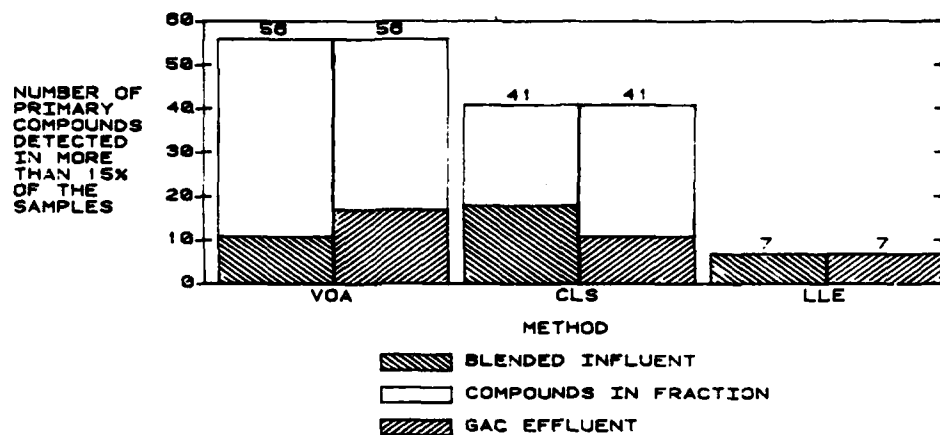
### THMs

The overall removals of THMs are listed in Tables 7.2-20 and 7.2-21 for Phases IA and IB, respectively. The negative percent removals shown in Table 7.2-20 indicate that the THM species were being formed during Phase IA. This was not unexpected, because chlorine was used for intermediate disinfection prior to filtration. In comparison, Table 7.2-21 shows that the THM species were removed during Phase IB, when the intermediate disinfectant was ozone.

Of the 151 primary organic compounds routinely monitored, excluding the four THMs discussed above, only nine compounds were regularly quantified in the blended influent during Phase IA. These compounds are listed in Table 7.2-22. The geometric mean concentrations of these compounds were all less than 1  $\mu\text{g/L}$  in the EEWTP blended influent.

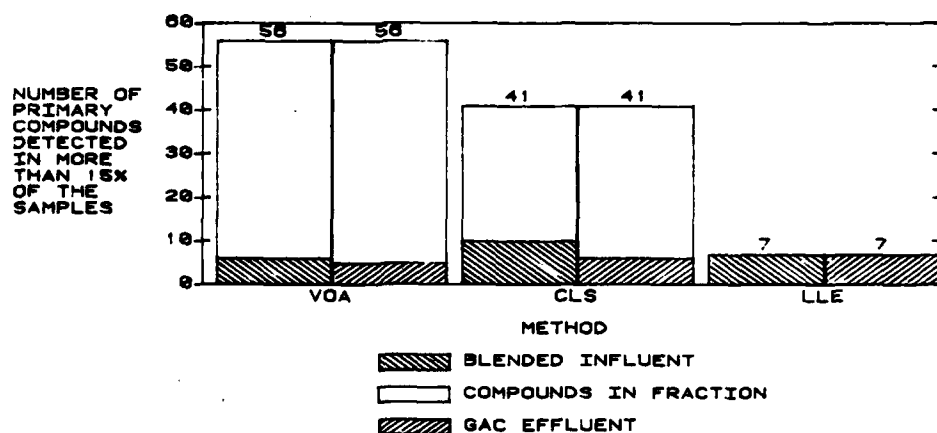
Only three of these compounds listed were detected in the GAC effluent at concentrations above the MDL in more than 15 percent of the samples. As shown, most of these compounds, with the exception of ethenylbenzene were reduced to levels below the IDLs by the treatment processes used in Phase IA. Because of the limited number of samples taken for closed loop stripping, the results have a high degree of uncertainty, as evidenced by very wide 95 percent confidence intervals. However, for the dichlorobenzene isomers, the treatment processes were quite effective. Based on the small numbers of primary organic compounds and the low levels detected in the blended influent, the results suggest that the Phase IA process provided adequate protection for control of the 151 primary organic compounds.





**OVERALL REMOVAL OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES (PHASE 1A)**

**FIGURE 7. 2-2**



**OVERALL REMOVAL OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES (PHASE 1B)**

**FIGURE 7. 2-3**

# Overall Plant Performance

TABLE 7.2-20  
OVERALL PLANT PERFORMANCE  
REMOVAL OF TRIHALOMETHANES  
PHASE IA

Parameter <sup>1</sup>	Blended Influent			GAC Effluent			Overall Removal %	95% Confidence Interval	
	N2	No. Detected	Geometric Mean	N	No. Detected	Geometric Mean		Lower	Upper
Chloroform IDL=0.1 µg/L	93	90	1.54	97	89	2.31	-50	-89	-19
Bromodichloromethane IDL=0.1 µg/L	93	44	0.27	97	69	0.64	-137	-207	-84
Dibromochloromethane IDL=0.1 µg/L	93	25	0.16	97	50	0.21	-31	-72	-0.4
Total Trihalomethanes IDL=0.1 µg/L	93	92	1.92	97	89	2.93	-53	-98	-17

1. Composite Samples by LLE.

2. N = Number of samples analyzed.

## Overall Plant Performance

TABLE 7.2-21  
OVERALL PLANT PERFORMANCE  
REMOVAL OF TRIHALOMETHANES  
PHASE IB

Parameter <sup>a</sup>	Blended Influent			GAC Effluent			Overall Removal %	95% Confidence Interval	
	N <sup>b</sup>	Detected	Geometric Mean	N	Detected	Geometric Mean		Lower	Upper
Chloroform IDL=0.1 µg/L	52	52	1.68	57	29	0.32	81.0	68.6	88.5
Bromodichloromethane IDL=0.1 µg/L	52	29	0.29	57	7	NC <sup>c</sup>	>65d	Not calculated	
Dibromochloromethane IDL=0.1 µg/L	52	14	0.09	57	7	NC	>-11d	Not calculated	
Total Trihalomethanes IDL=0.1 µg/L	52	52	2.11	57	33	0.28	87	78.6	91.8

a. Composite Samples by LLE.

b. N = Number of samples analyzed.

c. NC = Not calculated.

d. Overall removal calculated using the IDL as the effluent geometric mean.

## Overall Plant Performance

TABLE 7.2-22  
OVERALL PLANT PERFORMANCE  
REMOVAL OF QUANTIFIED PRIMARY ORGANIC COMPOUNDS  
(EXCLUDING THMs)  
PHASE IA

Parameter	Blended Influent			GAC Effluent			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	No Detected	Geometric Mean	N	No Detected	Geometric Mean		Lower	Upper
1,1,1-Trichloroethane (VOA) <sup>d</sup>	19	6	0.15	20	1	NC <sup>b</sup>	33.3 <sup>c</sup>	Not calculated	
IDL=0.1 µg/L									
Tetrachloroethene (LLE)	93	72	0.78	97	4	NC	87.2 <sup>c</sup>	Not calculated	
IDL=0.1 µg/L									
Ethylbenzene (CLS)	9	5	0.0224	9	6	0.0215	4.0	-144	62.3
IDL=0.005 µg/L									
Toluene (CLS)	9	6	0.118	9	2	0.073	38.1	-33	71.2
IDL=0.005 µg/L									
1,2-Xylene (CLS)	9	5	0.038	9	2	0.015	60.5	-99	92.2
IDL=0.005 µg/L									
1,2-Dichlorobenzene (CLS)	9	8	0.049	9	0	NC	99.8 <sup>c</sup>	Not calculated	
IDL=0.0001 µg/L									
1,3-Dichlorobenzene (CLS)	9	9	0.0752	9	0	NC	99.9 <sup>c</sup>	Not calculated	
IDL=0.0001 µg/L									

# Overall Plant Performance

TABLE 7.2-22 (Continued)  
OVERALL PLANT PERFORMANCE  
REMOVAL OF QUANTIFIED PRIMARY ORGANIC COMPOUNDS  
(EXCLUDING THMs)  
PHASE 1A

Parameter	Blended Influent			GAC Effluent			Overall Removal %	95% Confidence Interval	
	N <sup>a</sup>	Detected	Geometric Mean	N	Detected	Geometric Mean			
1,4-Dichlorobenzene (CLS) IDL=0.0001 µg/L	9	8	0.106	9	0	NC	99.9 <sup>c</sup>	Lower	Upper
1,2,4-Trichlorobenzene (CLS) IDL=0.001 µg/L	9	4	0.02	9	0	NC	99.5 <sup>c</sup>	Not calculated	Not calculated

a. N = Number of samples analyzed.

b. NC = Not calculated.

c. Overall removal calculated using the IDL as the effluent geometric mean.

d. Indicates method used. VOA = volatile organics analysis; LLE = liquid/liquid extraction; CLS = closed loop stripping.

## SECTION 3

### FATE OF CONTAMINANTS

This section evaluates the fate of selected water quality parameters which are of special interest or concern from a health, operational or aesthetic standpoint. The parameters discussed are classified according to the major groups established in Section 2.

#### PHYSICAL/AESTHETIC PARAMETERS

The parameters within this grouping that are discussed below include corrosivity, odor and turbidity. Corrosivity and odor are addressed here because they were of special concern during the first phase of operation. Turbidity is included because of its importance as a major operational and water quality parameter.

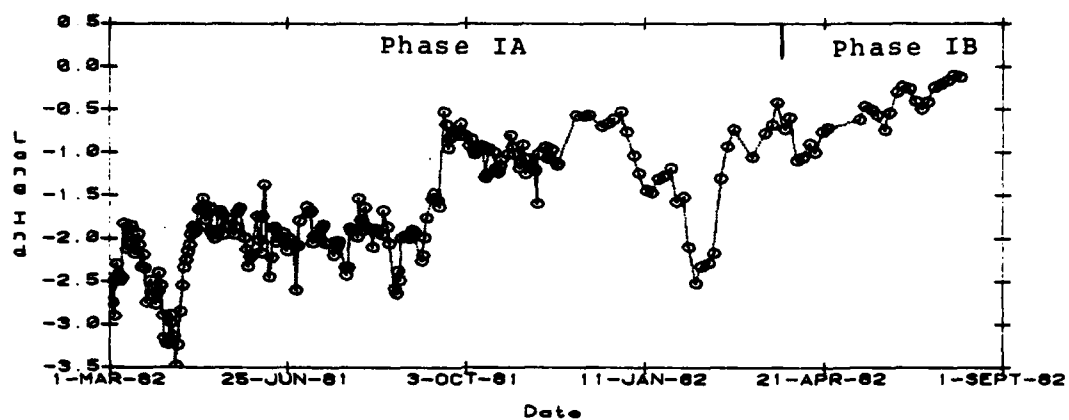
#### CORROSIVITY

The Langelier Index (LI) is a widely used measure of calcium carbonate ( $\text{CaCO}_3$ ) stability and is an empirical indicator of potential corrosivity in water. A positive value indicates that the water is oversaturated with  $\text{CaCO}_3$  and will potentially form scale. A negative value indicates that the water will dissolve  $\text{CaCO}_3$  and may be aggressive. A value of zero corresponds to stable water with respect to  $\text{CaCO}_3$  solubility.

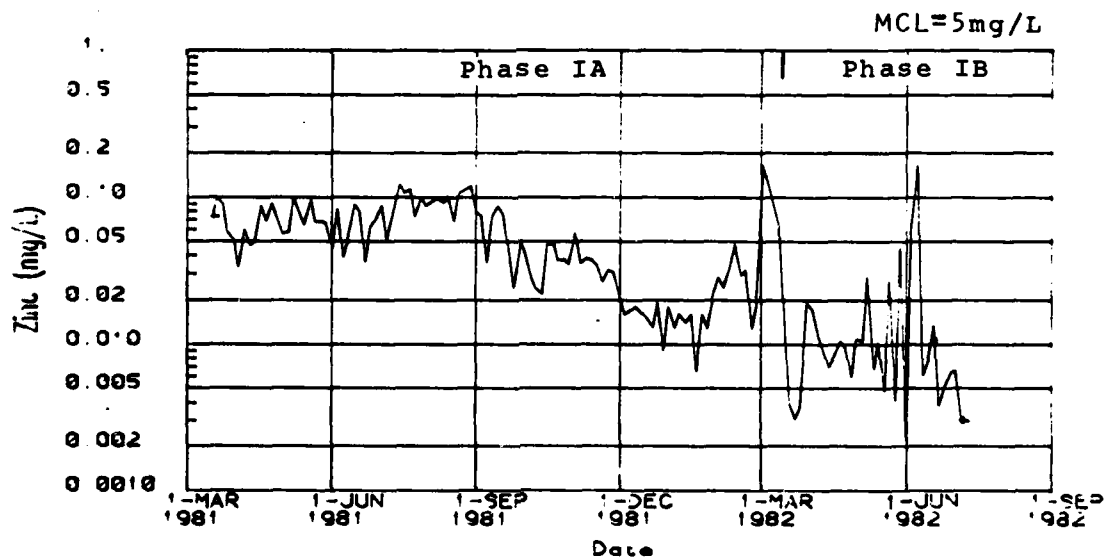
Figure 7.3-1 is a time series plot of LI values in the finished water during operating Phases IA and IB. These values, calculated as specified in the 15th Edition of Standard Methods, indicate that the EEWTP finished water was corrosive during the first six months of operation with LI values averaging approximately -2.0. The subsequent increases in the LI from early October 1981 through the remainder of Phases IA and IB correspond to operational changes made to increase the process water pH and reduce the corrosion potential.

A graphic illustration of the results of this effort are shown in Figure 7.3-2. The figure shows zinc values in the finished water during Phase IA and IB. The finished water zinc concentration, which was considerably higher than the influent concentration and indicates zinc dissolution within the plant, shows an inverse correlation to the LI. This correlation can also be demonstrated with other metals and is discussed in more detail in the Trace Metals section below.

A special study was undertaken midway through Phase IA to quantify the corrosion potential of the EEWTP finished water. Results of the study are presented in Chapter 10 and Appendix I.



**LANGELIER INDEX OF FINISHED WATER  
(PHASES IA AND IB)  
FIGURE 7. 3-1**



**FINISHED WATER ZINC CONCENTRATION  
(PHASES IA AND IB)  
FIGURE 7. 3-2**

### ODOR

Figure 7.3-3 presents a time series plot of the threshold odor number (TON) in the EEWTP finished water during operational Phases IA and IB. (The resolution of the plot reflects the frequency of analysis from daily to once per week). The TON of the finished water frequently exceeded the EPA Secondary Drinking Water MCL of 3 TON, and members of the odor panel often commented that the product water had a "chlorinous" aroma.

Examination of the time series plots of chlorine residual in Section 2 and TON reveals that the TON decreased significantly when the chlorine dose and pH were increased in early December of 1981. This suggests that the source of the odors may have been caused by products of chlorine and ammonia nitrogen reactions. It is possible that when the chlorine dose was increased to a point far exceeding the theoretical "breakpoint" (7.6 moles  $\text{Cl}_2$  to 1 mole  $\text{NH}_3\text{-N}$ ) that the intermediates of ammonia oxidation were at a minimum. Odor data from February 1981 further substantiate this, as ammonia was a major problem during this month and threshold odor numbers were very high.

Measurement of odor in water is very subjective and, therefore, the greatest utility of this test is as a comparative measure of odor. A discussion of odor comparisons between the EEWTP and the local water treatment plants is presented in Chapter 9.

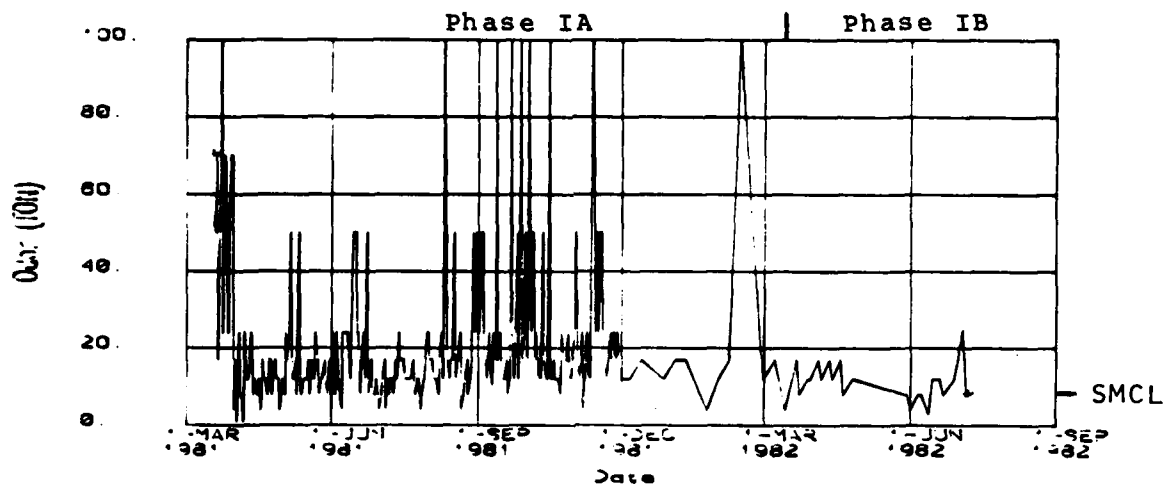
### TURBIDITY

Turbidity is a qualitative measurement of the suspended particulate matter (i.e., silt, microorganisms, organic detritus, etc.) in water and is a widely used parameter for water treatment process control and evaluation. Turbidity was measured more frequently than any other parameter at the EEWTP, and was used for control of the coagulation process and to initiate filter and carbon column backwashing.

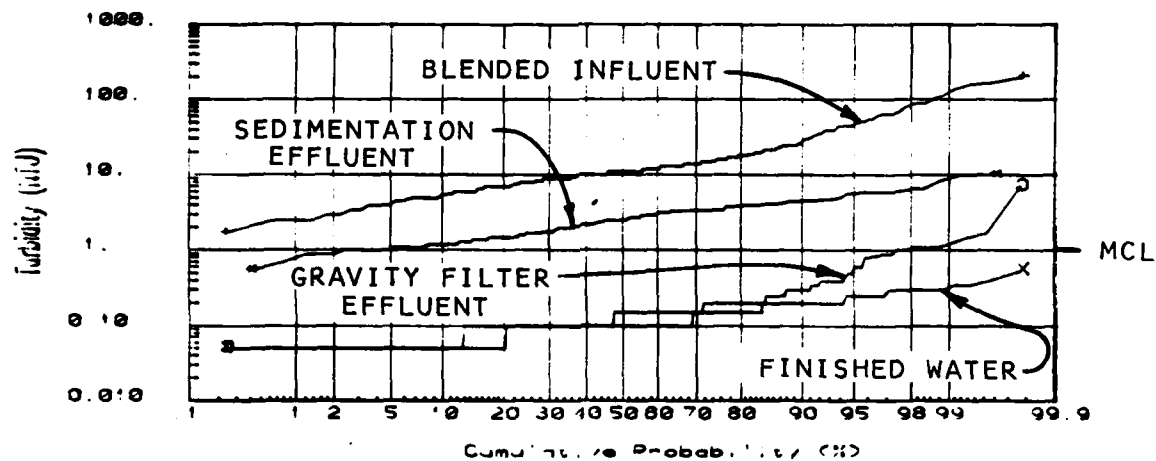
Figure 7.3-4 shows the cumulative frequency distributions of turbidity at four plant sites. Included are the blended influent, sedimentation effluent, gravity filter number one effluent and the finished water.

The turbidity of the raw water entering the plant was relatively low and had a geometric mean of 11.0 Nephelometric Turbidity Units (NTU) and a 90th percentile value of 22.0 NTU. The geometric mean of the sedimentation basin effluent was 3.04 NTU. Filter effluent and finished water turbidities were similar, with equivalent geometric means of 0.13 NTU. The turbidity of the finished water never exceeded the EPA primary MCL of 1 NTU during Phase IA. This was due, in part, to the GAC process which was capable of reducing the turbidity in the few cases when the gravity filter effluent exceeded 1.0 NTU.





**FINISHED WATER THRESHOLD ODOR NUMBER  
(PHASES IA AND IB)  
FIGURE 7. 3-3**



**DISTRIBUTION OF TURBIDITY  
(PHASES IA AND IB)  
FIGURE 7. 3-4**

## MAJOR CATIONS, ANIONS AND NUTRIENTS

The parameters of special concern in this group include ammonia, nitrate and sodium.

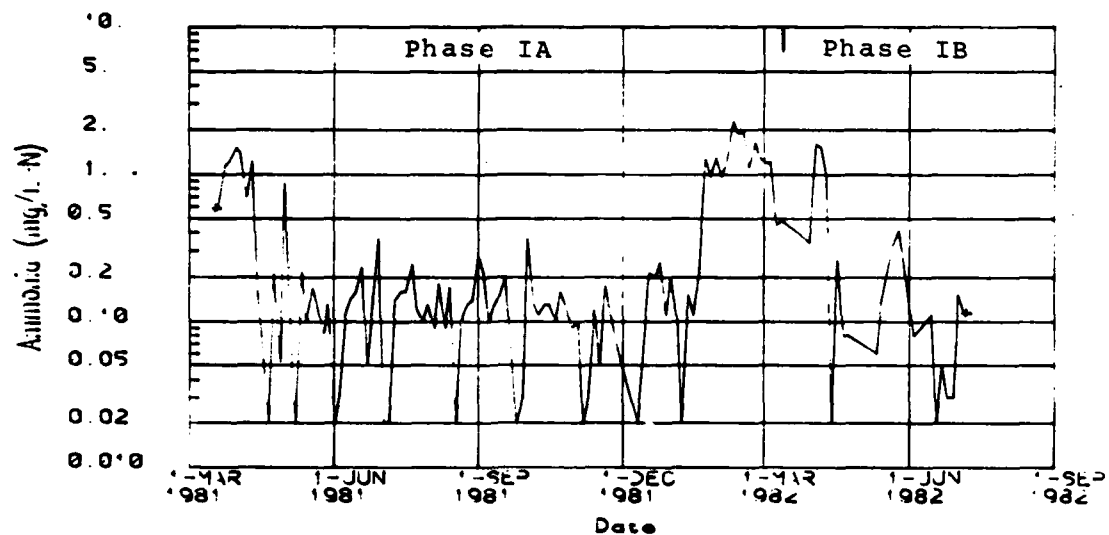
### AMMONIA

Ammonia is not considered to be a direct human health risk at concentrations typically found in most raw and finished drinking waters. However, because it readily reacts with chlorine, its presence can interfere with the chlorine disinfection process. This may result in reduced process efficiency and other secondary problems including increased chemical costs, taste and odor problems and growth of organisms within a distribution system. Ammonia was one of the most difficult operational problems encountered during Phase I of plant operation.

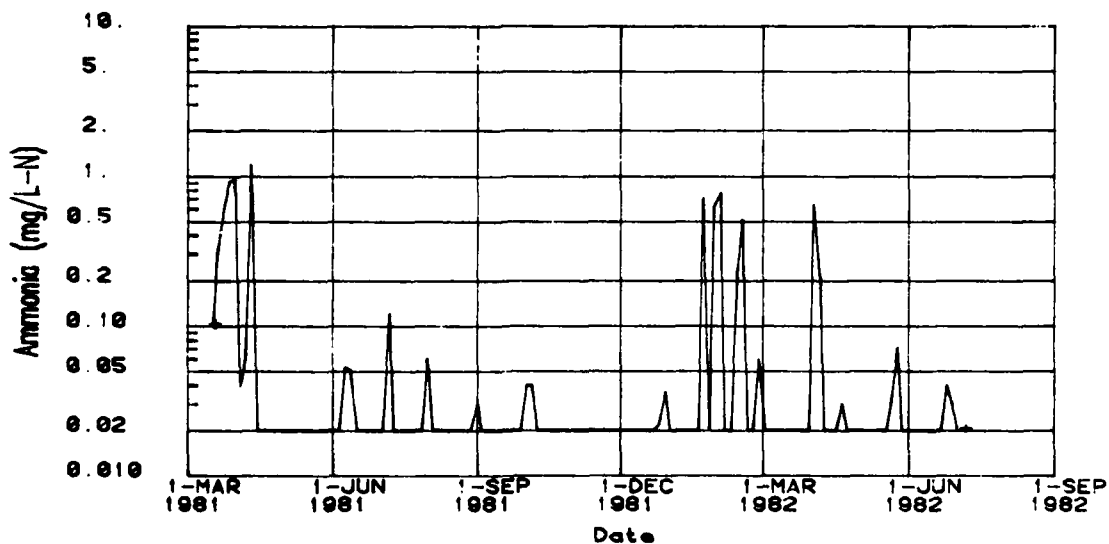
Both EEWTP raw water sources contained ammonia. In most cases, the concentrations of ammonia entering the plant were relatively low (approximately 0.1 mg/L-N) and easily removed. Removal occurred through biological nitrification on gravity filter and GAC media and by chemical oxidation with chlorine at the intermediate and final disinfection sites.

However, problems arose when upsets occurred in the Blue Plains nitrification process. During these periods, influent ammonia levels increased to the point where removal was difficult to control with the chlorination facilities at the EEWTP ( $>0.5$  mg/L-N). Figure 7.3-5(a) and (b) illustrate this point. Figure 7.3-5(a) is a time series plot of influent ammonia levels during Phases IA and IB. Figure 7.3-5(b) provides finished water ammonia concentrations for the same period. As shown in these figures, finished water ammonia concentrations were very erratic and much higher during the periods of increased influent ammonia concentration. Finished water microbiological quality deteriorated during these episodes, probably as a result of insufficient free chlorine residual (see Chapter 7, Section 4 and Chapter 9, Section 6 for details). In addition, other operational problems such as increased finished water corrosivity, total organic halide content, and odor occurred when applied chlorine dosages in the intermediate and final disinfection processes were increased to remove ammonia. The "Intermediate Disinfection-Chlorine" process description in Section 1 of this chapter details the operational strategies used to remove ammonia during this period.

Overall ammonia removal during Phases IA and IB exceeded ninety percent. However, evaluation of discrete, paired data at each sampling location, incorporating process variables such as temperature, pH and dissolved oxygen is necessary before removal efficiencies and conclusions can be drawn. Because significant levels of ammonia are likely to be present in the Potomac estuary, adequate provisions for removal must be considered in any future plant design.



(a) Blended Influent



(b) Finished Water

**BLENDED INFLUENT AND FINISHED WATER AMMONIA  
(PHASES IA AND IB)**

**FIGURE 7. 3-5**

## Fate of Contaminants

### NITRATE

Nitrate is of special health concern in drinking water because large concentrations have been related to the induction of methemoglobinemia (a reduction in the oxygen carrying capacity of the blood) in infants. Evidence also suggests, that under the proper conditions, ingested nitrates can be converted to potentially carcinogenic compounds (NAS, Drinking Water and Health, 1977). As a result, the U.S. EPA has established a Primary Drinking Water MCL of 10 mg/L for nitrate.

Figure 7.3-6 is a time series plot of nitrite and nitrate in the EEWTP finished water. The figure shows that the nitrate levels were typically sixty to eighty percent of the MCL with occasional wide variations in concentration caused by one of the influent sources being out of service. For example, the high concentration spike which occurred in early June coincided with a break in the estuary line and the resultant use of 100 percent nitrified effluent. This episode caused finished water nitrate levels to exceed the MCL for several days. Conversely, the low levels of nitrate corresponded to the periods when 100 percent estuary water was used.

Virtually none of the nitrate entering the plant was removed by the treatment processes employed during operation of the EEWTP. In fact, the nitrate levels tended to increase slightly due to biological and chemical oxidation of ammonia in the GAC and chlorination process.

Nitrate removal by reverse osmosis was evaluated and verified at the EEWTP. The results of the study, which was conducted on a 7 gpm sidestream, are presented in Chapter 10, Section 5.

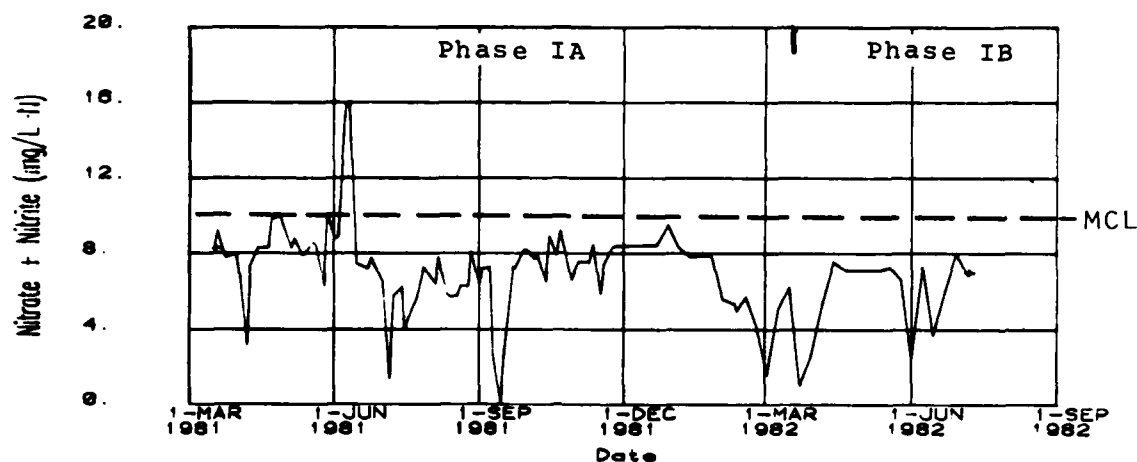
### SODIUM

Because excessive sodium intake has been linked to hypertension in susceptible people (NAS, Drinking Water and Health, 1977), the EPA has promulgated a monitoring program requiring water supply systems to annually check sodium levels in surface waters. EPA also suggests that the optimal sodium concentration in drinking water be 20 mg/L or less (EPA, 1980).

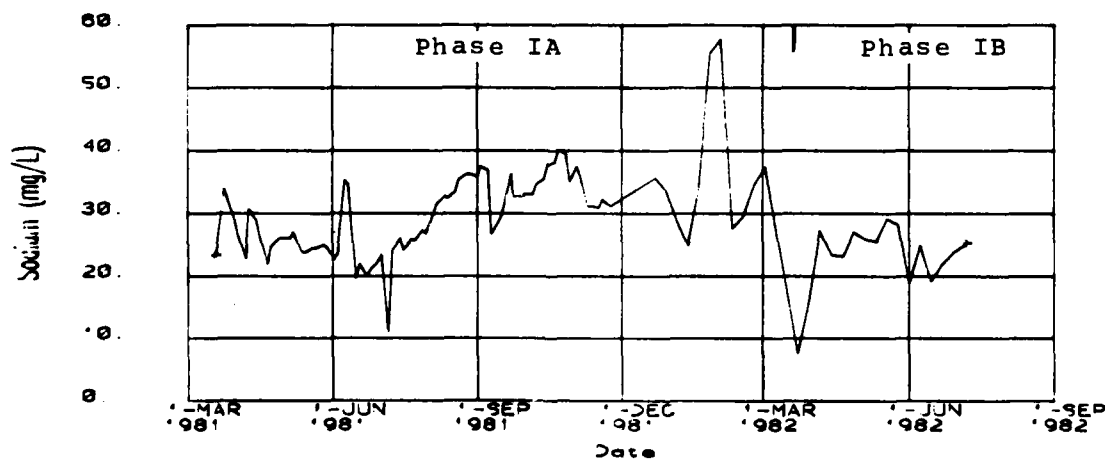
Figure 7.3-7 is a time series profile of sodium in the EEWTP finished water. As shown in the figure, the sodium concentrations varied considerably, but were consistently above the suggested 20 mg/L with a maximum value over 50 mg/L.

Geometric mean values for sodium entering the plant from Blue Plains and the Potomac Estuary were approximately 45 and 15 mg/L, respectively. Sodium levels tended to increase in the winter months. This may have been a result of run-off containing salt from road maintenance and deicing operations. Addition of sodium hydroxide as a pH adjustment chemical late in February 1982 also caused a slight increase in the sodium content of the EEWTP finished water.

Sodium, like many of the parameters in this group, cannot be removed by the full-scale treatment processes used at the EEWTP, and therefore, alternative



**FINISHED WATER NITRITE + NITRATE CONCENTRATION  
(PHASES IA AND IB)  
FIGURE 7. 3-6**



**FINISHED WATER SODIUM CONCENTRATION  
(PHASES IA AND IB)  
FIGURE 7. 3-7**

## Fate of Contaminants

treatment schemes or sources must be used if finished water levels are to be maintained below 20 mg/L.

### TOTAL DISSOLVED SOLIDS

Figure 7.3-8 is a time series plot of the total dissolved solids (TDS) concentration in the EEWTP finished water in Phases IA and IB. TDS is a measure of the soluble salt content in water for which an SMCL of 500 mg/L has been established. As in the case of most of the minerals in this parameter group, the full-scale treatment processes used at the EEWTP were unable to remove any of the TDS in the plant influent. The water treatment chemicals used (alum, lime, chlorine, etc.) increased the level of TDS in the finished water. However, as shown in the figure, the finished water TDS concentration was consistently below the 500 mg/L standard.

### TRACE METAL PARAMETERS

This section describes the fate of selected trace metals during Phase IA and IB of operation, and discusses issues related to their occurrence. Metals chosen for discussion were selected because their concentrations may have occasionally exceeded drinking water MCLs or they may have exceeded levels found in finished waters of the local plants used for comparison.

Antimony, iron, lead, manganese, mercury, nickel, selenium, and zinc were the metals in the EEWTP finished water that exceeded concentrations in the local plants at the geometric mean level.

Lead, mercury and selenium are regulated under the NIPDWR. Although their concentrations exceeded those occurring in the local plants, they were well below the maximum allowable concentrations. It is also important to note that there were two major causes for the higher concentration of metals in the EEWTP effluent, especially during Phase IA. These included a low process water pH, during the first several months of operation, and use of one influent source.

The corrosivity of the finished water was discussed in the Physical/Aesthetic portion of this section. As noted there, zinc concentrations in the finished water could be inversely correlated with the Langlier Index. The source of the zinc and perhaps some of the other metals such as iron, that increased in the plant may be attributed to the galvanized angle iron braces that were used to support the wooden baffles in the chlorine contact tank.

The use of only one raw water source also caused considerable variation in some effluent metal concentrations. Inspection of the data revealed that the periods of highest concentrations of antimony, iron, lead, manganese, nickel and selenium in the finished water corresponded to the periods of time when only one source was used. A more detailed evaluation of lead, manganese and selenium is presented below.



## Fate of Contaminants

### LEAD

Figure 7.3-9 shows the cumulative probability of lead concentrations at three points in the treatment process. The figure illustrates that lead was readily removed by the coagulation and gravity filtration processes.

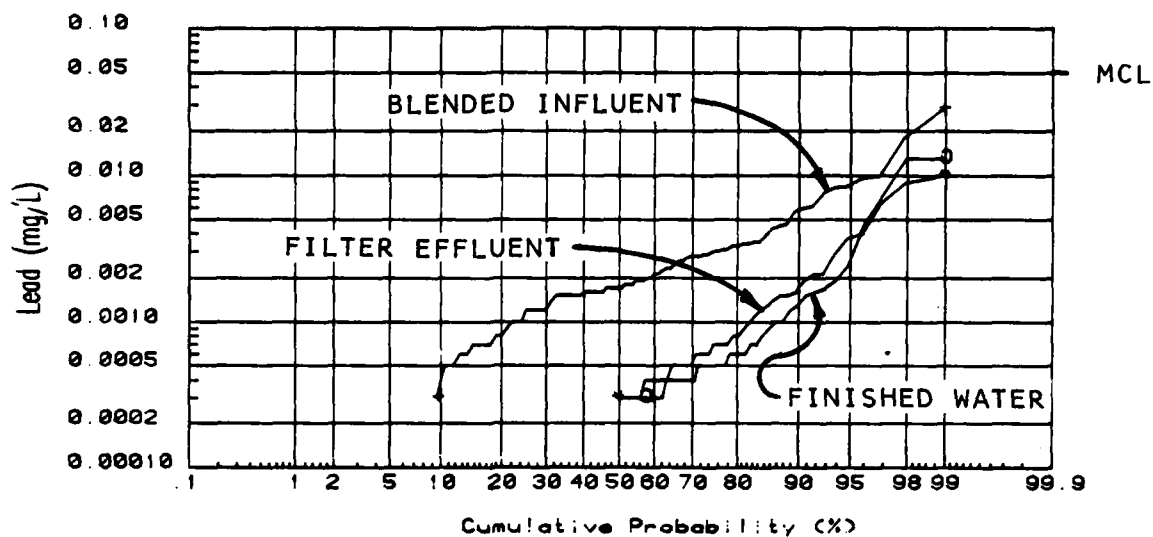
### MANGANESE

The time series behavior of manganese concentrations at three EEWTP sites is shown in Figures 7.3-10(a), (b), and (c). The figures illustrate the effect of different operating strategies on manganese concentrations throughout the plant. The major operational changes instituted for the study and control are discussed in detail in Chapter 10, Section 7 and Appendix I and are outlined below in Table 7.3-1.

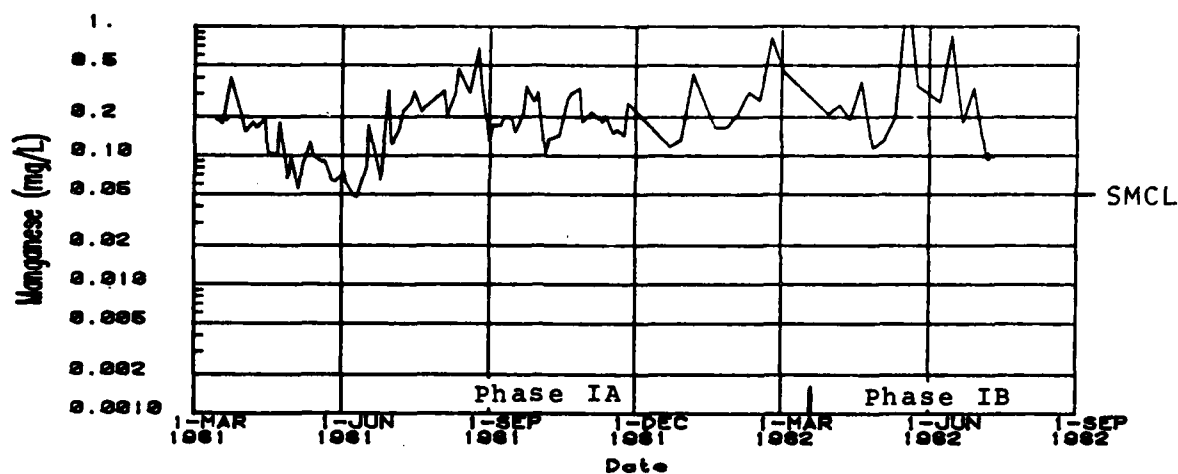
TABLE 7.3-1  
OPERATIONAL CHANGES FOR MANGANESE CONTROL

Period	Operating Conditions	
1. 3/16 to 5/31/81	No pH control	No oxidant used
2. 6/1 to 6/15/81	No pH control	KMnO <sub>4</sub> addition at rapid mix no. 1
3. 6/16 to 9/19/81	No pH control	KMnO <sub>4</sub> addition at the aeration basin
4. 9/20 to 10/30/81	pH control prior to coagulation to offset pH drop caused by alum addition	KMnO <sub>4</sub> addition at the blend tank
5. 11/1/81 to 1/24/82	pH control at sed basin effluent, target pH=8.0	KMnO <sub>4</sub> at blend tank
6. 1/24 to 3/16/82	pH control at sed basin effluent, target pH=8.0	No KMnO <sub>4</sub>
7. 3/17/82 to 7/7/83	pH control at sed basin effluent, target pH=8.0	Ozone at 4 mg/L prior to filtration

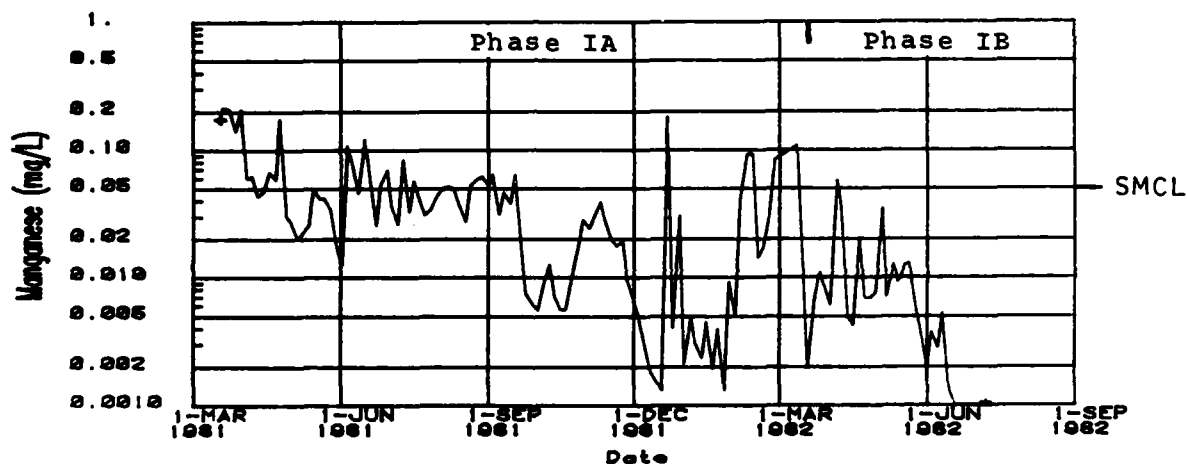




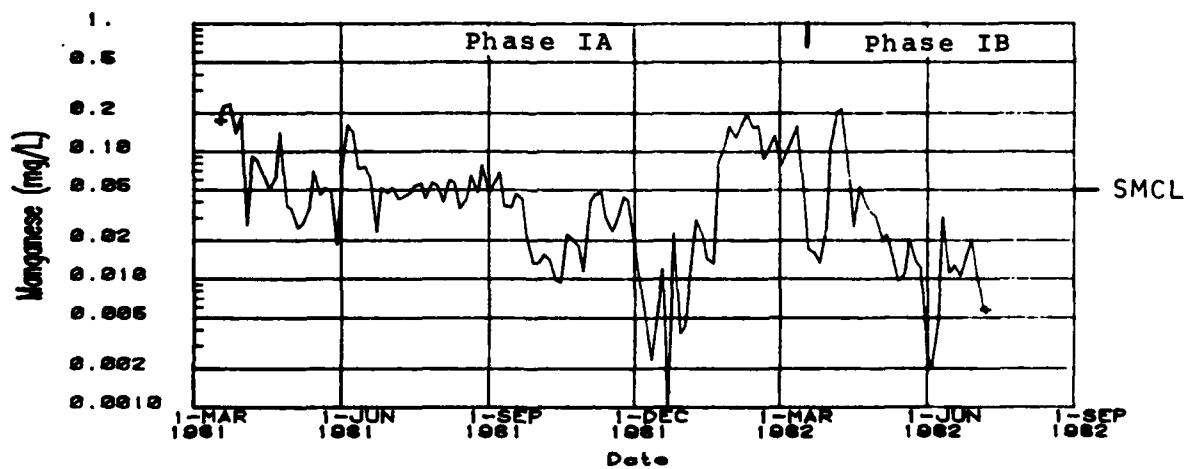
**DISTRIBUTION OF LEAD  
(PHASE IA)  
FIGURE 7. 3-9**



(a) Blended Influent



(b) Filter Effluent



(c) Finished Water

**MANGANESE CONCENTRATIONS AT THREE EEWTP SITES  
(PHASES IA AND IB)  
FIGURE 7.3-10**

## SELENIUM

Figure 7.3-11 presents cumulative probability plots of selenium concentrations at three points in the process treatment scheme. These curves show that the selenium concentration increased slightly in the finished water with respect to the blended influent.

## MICROBIOLOGICAL PARAMETERS

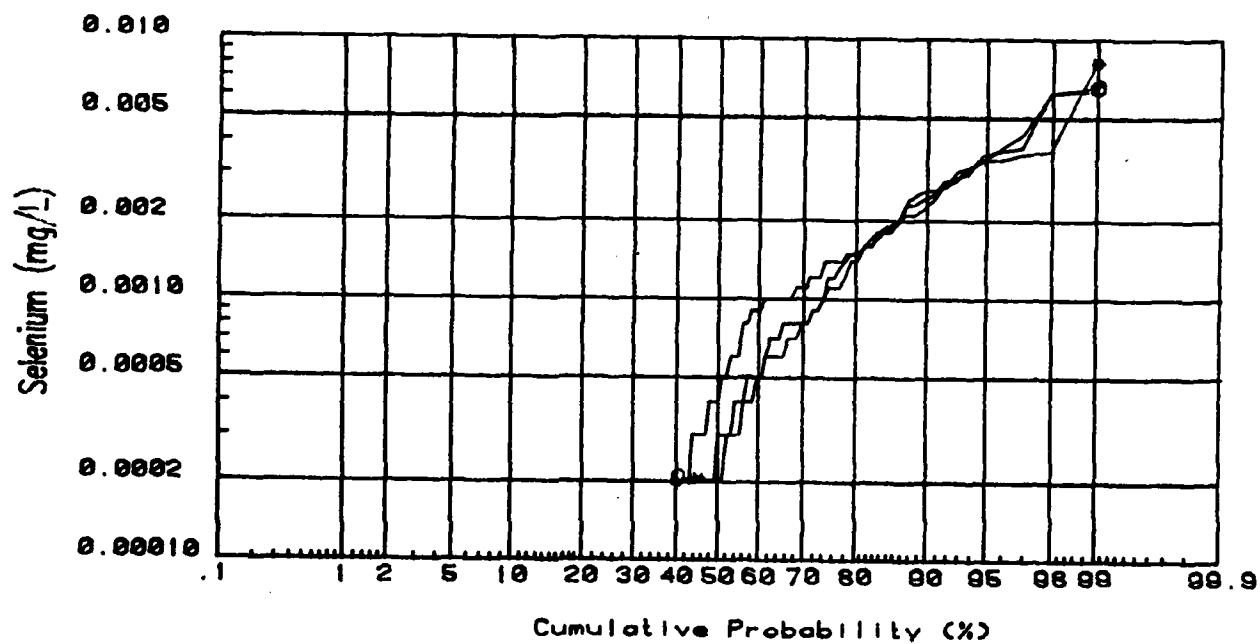
Overall performance of the EEWTP was presented in Section 2 of this chapter for all microbiological parameters monitored in the blended influent and finished water. Process performance through the plant for those microbiological parameters frequently monitored at EEWTP process sampling locations is evaluated in this section. The parameters evaluated are total coliforms and standard plate count bacteria (SPC), both of which were consistently detected in samples from each of the monitored locations ahead of the final disinfection stage. Parasite organisms, enteric viruses and Salmonella are not included in this section. Parasites were not detected in any Phase IA EEWTP samples and viruses and Salmonella only in the blended influent. Also, these parameters were not monitored at any sites between the influent blend and finished water during Phase IB.

The effectiveness of individual EEWTP processes in removing bacteriological contaminants was evaluated using cumulative probability distribution plots. Variability is represented graphically by the slope of the plot while the range is reflected by ten percent and ninety percent values. The geometric mean was used to assess process performance in terms of the number of logs of bacteria removed through the individual processes. The  $\log_{10}$  value of the ratio of the process influent to process effluent geometric means was termed the geometric mean log removal.

The following sites monitored during Phase IA and IB provided data for evaluating individual processes and groups of processes:

<u>Sampling Location at Influent to Process</u>	<u>Sampling Location at Effluent of Process</u>	<u>Unit Processes Evaluated</u>
1. EEWTP blended influent	Gravity filter effluent	Coagulation, sedimentation, intermediate disinfection and filtration
2. Gravity filter effluent	Final carbon effluent	GAC
3. Final carbon column effluent	Finished water	Disinfection

Tables 7.3-2 and 7.3-3 summarize total coliform and SPC statistical parameters for Phases IA and IB.



**DISTRIBUTION OF SELENIUM AT THREE EEWP SITES  
(PHASE 1A)**

**FIGURE 7. 3-11**

### TOTAL COLIFORMS

Total coliforms were monitored daily (five samples/week) at the carbon column effluent and finished water locations during Phase IA except that monitoring at the carbon column location was reduced to weekly samples between 1 December 1981 and 16 March 1982. Both locations were monitored daily during Phase IB (16 March - 7 July 1982). Weekly sampling at the EEWTP blended influent and dual media filtration sites began on 1 December 1981 and remained at this frequency through Phase IB. This created a disparity in the number of data points available for characterizing the performance of the GAC columns where only fifteen filter effluent samples were analyzed in Phase IA whereas 223 carbon column effluent samples were analyzed during the same period. To resolve this issue, individual filter effluent data points were matched with the GAC data collected and analyzed on the same days. Geometric means were calculated from both sub-set populations and compared to the means determined from the total sample population.

### Cumulative Process Evaluation

Cumulative process removal of total coliforms in terms of geometric mean log removal is presented in Table 7.3-4 for Phases IA and IB. The log reductions presented in this table and in Table 7.3-5 were calculated from the data presented in Tables 7.3-2 and 7.3-3. The 5.5 logs removed through the coagulation, intermediate disinfection and filtration stages in IA represent a 99.9997 percent reduction of the total coliform geometric mean concentration observed in the blend. This removal was lower in Phase IB amounting to a 2.9 log or 99.8727 percent reduction. The cumulative log removal after the carbon columns decreased in Phase IA indicating that the geometric mean concentration in the carbon column effluent was greater than in the dual media filter effluent. This phenomenon of increasing total coliform counts after GAC treatment is discussed in Section 4. The overall performance for both phases was similar, with 6.3 log and 6.4 log removals for IA and IB, respectively.

### Individual Process Evaluation

Distribution plots of total coliform results at individual process sites are presented in Figure 7.3-12 (Phase IA) and 7.3-13 (Phase IB). The individual process removals are presented in Table 7.3-5.

TABLE 7.3-2

PROCESS PERFORMANCE  
MICROBIOLOGICAL PARAMETERS  
PHASE 1A

<u>Total Coliforms (MPN/100 ml)</u>		<u>EEWTP Blended Influent 1</u>	<u>Gravity Filter Effluent 1</u>	<u>Final Carbon Column Effluent</u>	<u>EEWTP Finished Water</u>	<u>Overall Log Reduction</u>
<u>Number of Samples</u>		15	15	223	255	
<u>No. Detected</u>		15	8	221	181	
<u>Geometric Mean</u>		$6.4 \times 10^4$	$2 \times 10^{-1}$	3.2	$3.1 \times 10^{-2}$	6.3
<u>Median</u>		$5.4 \times 10^4$	$2 \times 10^{-1}$	3.3	$2 \times 10^{-2}$	6.4
<u>90% Value</u>		$3.5 \times 10^5$	1.1	$1.3 \times 10^1$	$1.4 \times 10^{-1}$	6.4
<u>Standard Plate Count (CFU/ml)</u>						
<u>Number of Samples</u>		14	16	186	258	
<u>No. Detected</u>		14	14	175	58	
<u>Geometric Mean</u>		$2.9 \times 10^4$	6.1	$1.2 \times 10^2$	$2 \times 10^{-1}$	5.2
<u>Median</u>		$3.2 \times 10^4$	$1.1 \times 10^1$	$1.4 \times 10^2$	<1	>4.5
<u>90% Value</u>		$8 \times 10^4$	$2.2 \times 10^1$	$2.8 \times 10^3$	2	4.6

1. Weekly analysis began at these sites on 1 December 1981.

TABLE 7.3-3  
PROCESS PERFORMANCE  
MICROBIOLOGICAL PARAMETERS  
PHASE IB

	EEWTP Blended Influent <sup>1</sup>	Gravity Filter Effluent <sup>1</sup>	Final Carbon Column Effluent	EEWTP Finished Water	Overall Log Reduction
<u>Total Coliforms (MPN/100 ml)</u>					
Number of Samples	13	15	72	68	
No. Detected	13	15	72	19	
Geometric Mean	2.2x10 <sup>4</sup>	2.8x10 <sup>1</sup>	9.4	8x10 <sup>-3</sup>	6.4
Median	2.2x10 <sup>4</sup>	5.4x10 <sup>1</sup>	8.4	<1.8x10 <sup>-2</sup>	>6.1
90% Value	3.5x10 <sup>4</sup>	2.4x10 <sup>2</sup>	3.5x10 <sup>1</sup>	2x10 <sup>-2</sup>	6.2
<u>Standard Plate Count (CFU/ml)</u>					
Number of Samples	13	14	74	75	
No. Detected	13	14	74	16	
Geometric Mean	1.6x10 <sup>4</sup>	4.8x10 <sup>2</sup>	1.75x10 <sup>2</sup>	4x10 <sup>-1</sup>	4.6
Median	1.4x10 <sup>4</sup>	2.5x10 <sup>2</sup>	1.54x10 <sup>2</sup>	<1	>4.1
90% Value	3.8x10 <sup>4</sup>	3.7x10 <sup>3</sup>	6.9x10 <sup>2</sup>	2	4.3

1. Weekly analysis at these sites began on 1 December 1981.

## Fate of Contaminants

TABLE 7.3-4  
CUMULATIVE REMOVAL OF TOTAL COLIFORMS  
PHASES IA AND IB

	Cumulative Geometric Mean Log Reduction		
	Gravity Filter Effluent <sup>1</sup>	GAC Effluent	Finished Water
Phase IA	5.5	4.3	6.3
Phase IB	2.9	3.4	6.4

1. The gravity filtration effluent has been treated using the following processes: alum coagulation, sedimentation, intermediate disinfection and dual media filtration.

TABLE 7.3-5  
REMOVAL OF TOTAL COLIFORMS  
BY EEWTP PROCESSES

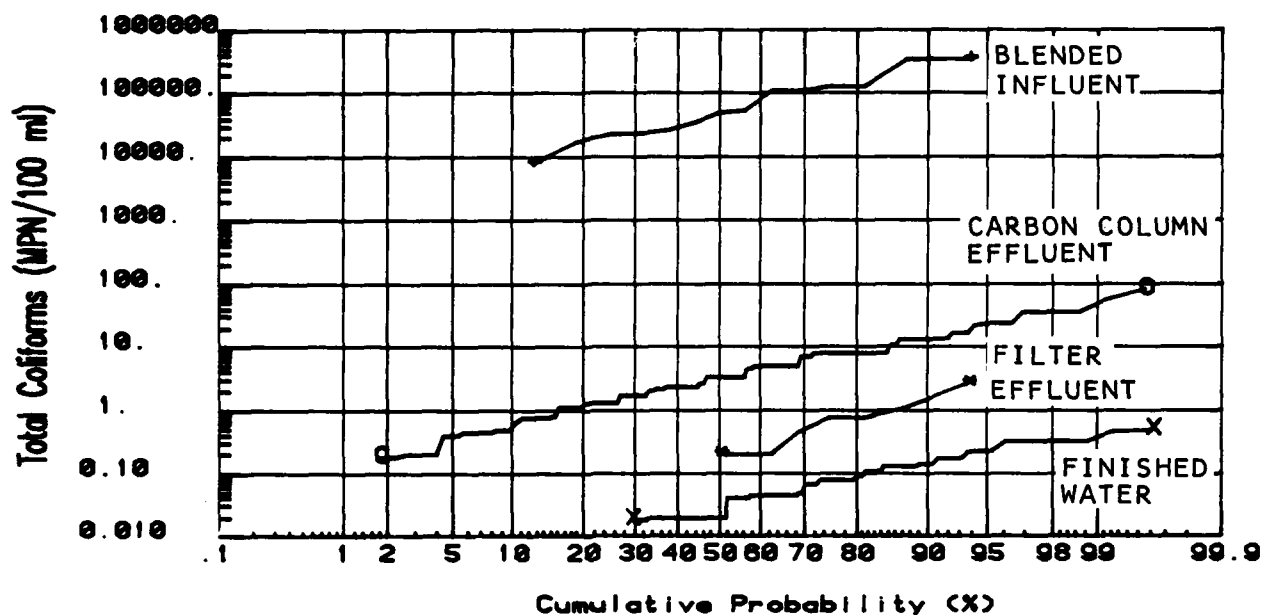
Process(es)	Geometric Mean Log Removal		Geometric Mean Percent Removal	
	Phase IA	Phase IB	Phase IA	Phase IB
Through Filtration	5.5	2.9	>99	>99
Through GAC	-1.2	0.5	-1500 <sup>a</sup>	66
Final Disinfection	2.0	3.1	>99	>99

- a. There was a 1,500 percent increase in total coliforms through GAC .

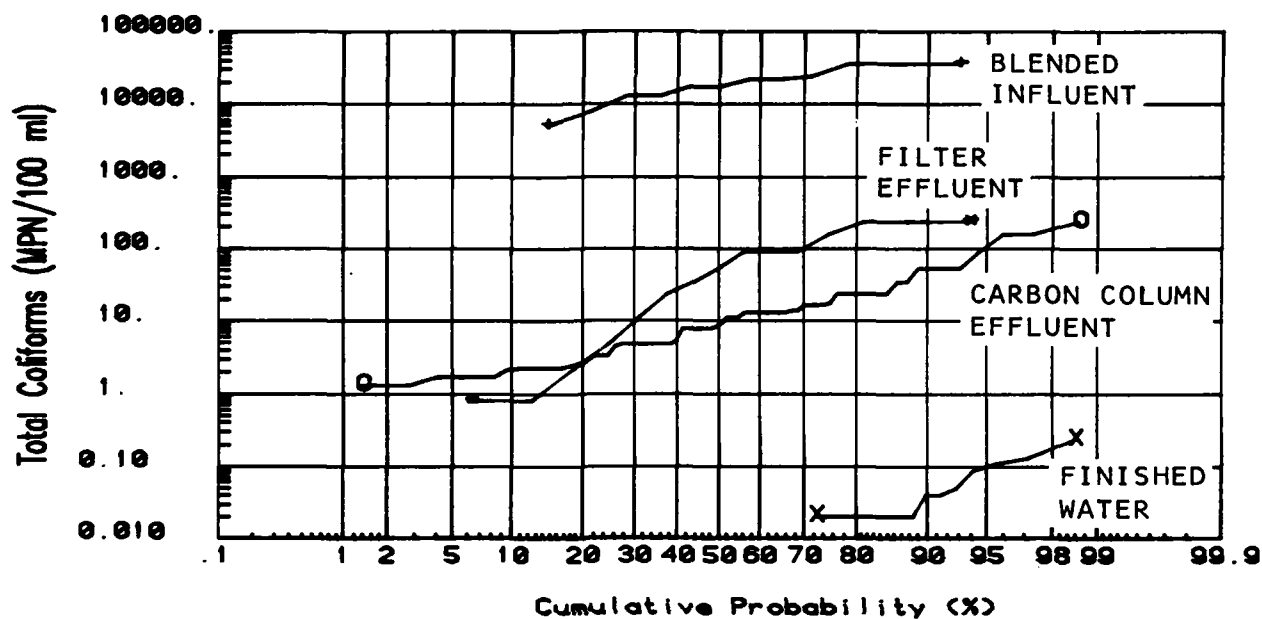
Figure 7.3-12 (Phase IA) demonstrates that the total coliform concentration after carbon treatment was greater than the concentration entering the carbon columns from the dual media filter effluent. Because of the disparity between the number of samples collected at each site, Phase IA dual media filter data points were paired by collection date with the carbon column effluent data points and the geometric mean was calculated using the available fourteen paired samples. The geometric mean log increase through the columns was 1.4 for the paired data compared to 1.2 using all the data.

Final disinfection removed 2.0 and 3.1 logs of total coliforms in Phases IA and IB, respectively. The less effective final disinfection in Phase IA accounts for the higher frequency of total coliform detection observed during the first several months of Phase IA operations as discussed in Chapter 9 (Section 6) - "Evaluation of Finished Waters." A detailed discussion of final disinfection is presented in Section 4 of this chapter.





**DISTRIBUTION OF  
TOTAL COLIFORM BACTERIA  
(PHASE IA)  
FIGURE 7. 3-12**



**DISTRIBUTION OF TOTAL COLIFORM BACTERIA  
(PHASE IB)  
FIGURE 7. 3-13**

## STANDARD PLATE COUNT (SPC) BACTERIA

SPC samples were monitored at the same sites and sampling frequencies as total coliforms during Phases IA and IB. Both analyses were conducted using aliquots from the same containers.

Cumulative Process Evaluation

Cumulative process removal of SPC bacteria is shown in Table 7.3-6 for both phases of operation. The geometric mean concentration increased through the carbon columns in Phase IA, but not in IB. Phase IA removal through coagulation/intermediate disinfection/filtration was more effective by approximately two logs of bacteria compared to Phase IB performance of this group of processes. These observations were true for final coliforms, as previously described.

Individual Process Evaluation

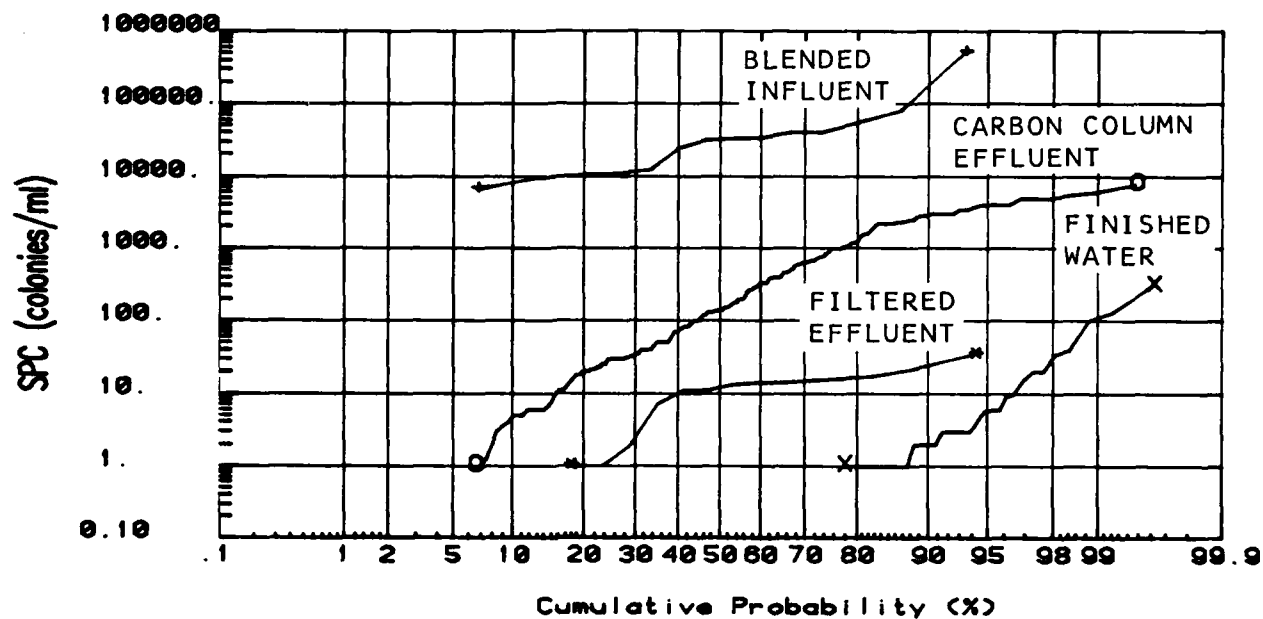
Evaluation of the individual processes to remove SPC is shown in Tables 7.3-6 and 7.3-7 and Figures 7.3-14 and 7.3-15.

The SPC concentration increase observed through the carbon columns during Phase IA was evaluated by the same procedure described for total coliforms using fourteen paired samples. The geometric mean increase through the carbon columns was 1.4 logs of SPC bacteria compared to a 1.3 log increase using all the data.

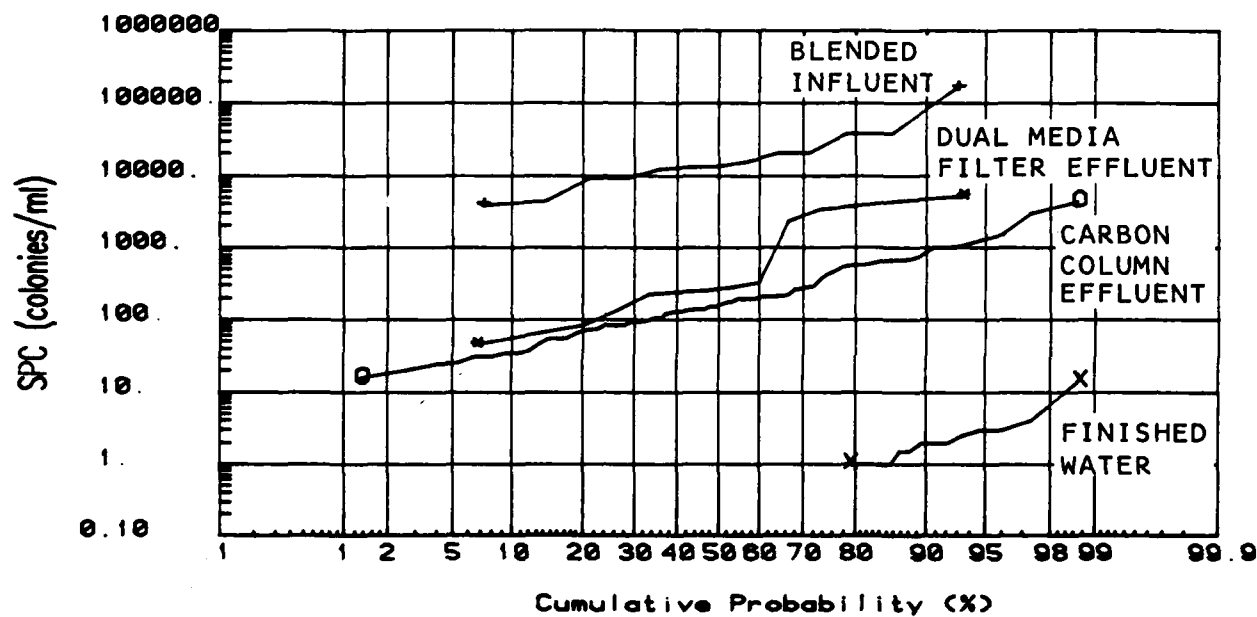
TABLE 7.3-6  
CUMULATIVE REMOVAL OF SPC BACTERIA  
PHASES IA AND IB

	<u>Cumulative Geometric Mean Log Reduction</u>		
	<u>Dual Media Filtration Effluent<sup>1</sup></u>	<u>GAC Effluent</u>	<u>Finished Water</u>
Phase IA	3.7	2.4	5.2
Phase IB	1.5	2.0	4.6

1. The dual media filtration effluent has been treated using the following processes: alum coagulation, sedimentation, intermediate disinfection and dual media filtration.



**DISTRIBUTION OF  
 STANDARD PLATE COUNT BACTERIA  
 (PHASE IA)  
 FIGURE 7. 3-14**



**DISTRIBUTION OF  
 STANDARD PLATE COUNT BACTERIA  
 (PHASE IB)  
 FIGURE 7. 3-15**

## Fate of Contaminants

TABLE 7.3-7  
REMOVAL OF SPC BY EEWTP PROCESSES

<u>Process(es)</u>	<u>Geometric Mean Log Removal<sup>1</sup></u>		<u>Geometric Mean Percent Removal</u>	
	<u>Phase IA</u>	<u>Phase IB</u>	<u>Phase IA</u>	<u>Phase IB</u>
Through Filtration	3.7	1.5	>99	97
Through GAC	1.3	0.4	(1867) <sup>2</sup>	64
Final Disinfection	2.8	2.6	>99	>99

1. Negative values (-) indicate SPC removal, positive values (+) indicate a concentration increase through the process.
2. There was a 1876 percent increase in SPC through GAC.

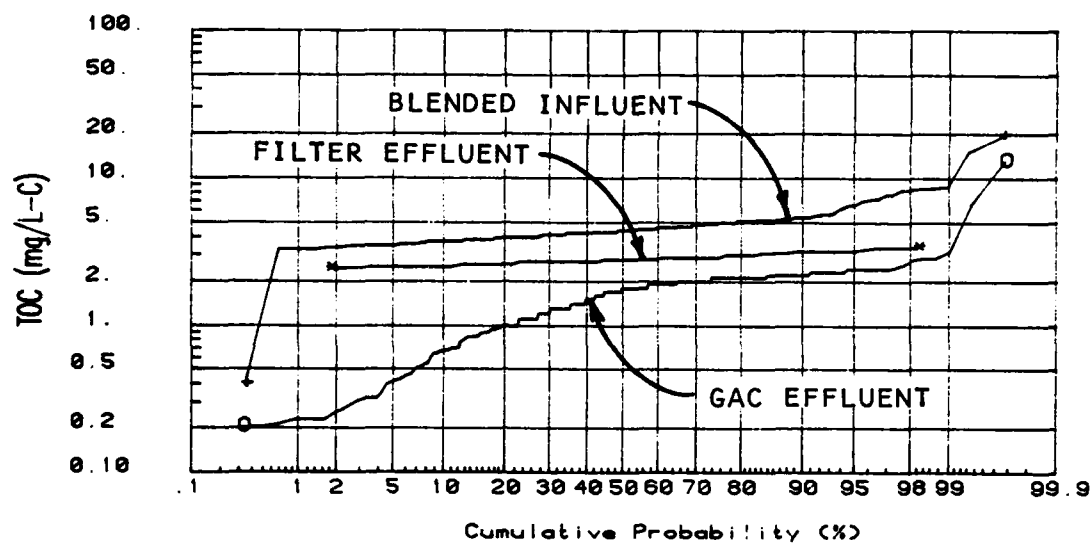
## ORGANIC PARAMETERS

This section describes the effects of individual unit processes at the EEWTP on the removal and/or formation of organic compounds during the alum operation modes. Cumulative probability plots of the concentration of selected organic parameters illustrate these effects.

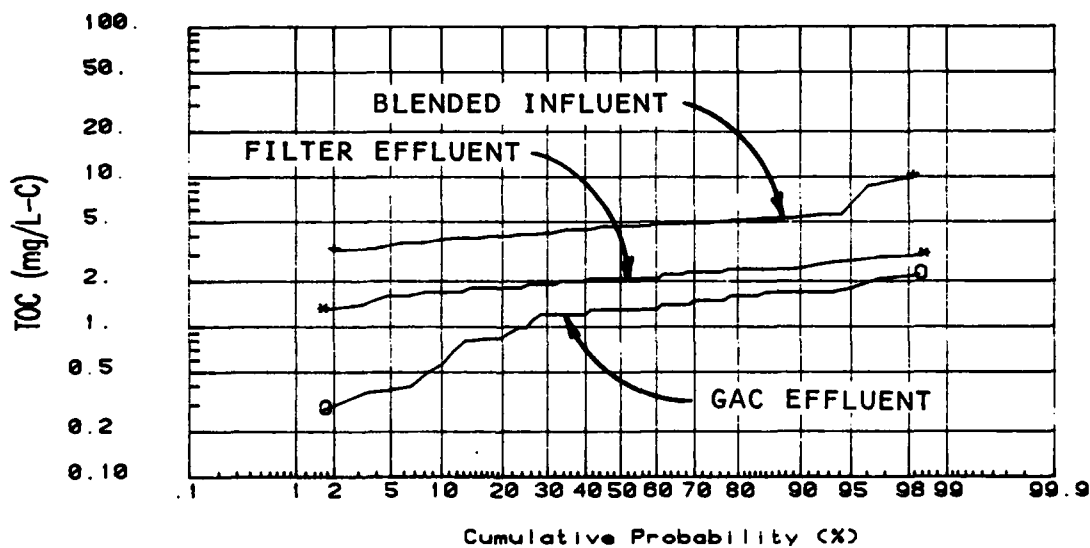
### SURROGATE PARAMETERS

#### TOC

The distribution of TOC at three sampling sites within the EEWTP is shown in Figures 7.3-16 and 7.3-17 for Phases IA and IB, respectively. Based on the geometric mean concentration listed in Appendix Table G-1-9, similar amounts of TOC were removed by coagulation/flocculation/sedimentation/filtration and by GAC during Phase IA. The variability of TOC concentrations was greater after GAC in Phase IA. Figure 7.3-17 shows that a larger fraction of blended influent TOC was removed by coagulation/flocculation/sedimentation/filtration in Phase IB than by GAC.



**DISTRIBUTION OF TOC  
(PHASE IA)  
FIGURE 7. 3-16**



**DISTRIBUTION OF TOC  
(PHASE IB)  
FIGURE 7. 3-17**

## TOX

The effect of coagulation/flocculation/sedimentation on TOX is shown in Figure 7.3-18. Although the figure shows data for Phase IA only, small removals of TOX by these processes, relative to downstream unit processes, were observed in both phases.

The effect of GAC on the distribution of TOX is shown in Figures 7.3-19 and 7.3-20 for Phases IA and IB, respectively. A comparison of the median TOX concentration in the filter effluent, in Figure 7.3-19, and sedimentation effluent, in Figure 7.3-18, for Phase IA shows that the TOX concentration increased through filtration. This was expected, because chlorine was used prior to filtration as an intermediate disinfectant during this phase. Figure 7.3-20 shows that TOX concentrations in the filter effluent were lower during Phase IB than IA, due to intermediate disinfection with ozone. In both phases, the fractional removal of TOX by GAC was approximately fifty percent as measured by the geometric mean concentration listed in Tables G-1-9 and G-2-9.

The effect of final chlorination on the distribution of TOX is shown in Figure 7.3-21 and 7.3-22 for Phases IA and IB, respectively. In both phases, the geometric mean TOX concentration was approximately doubled by final disinfection with chlorine.

The quantity of TOX formed by chlorination was approximately 24.8  $\mu\text{g-Cl/mg-C}$  for Phase IA and 13.1  $\mu\text{g-Cl/mg-C}$  for Phase IB, based on geometric mean values of TOX at both sites and the geometric mean values of TOC in the GAC effluent.

## PRIMARY ORGANIC COMPOUNDS

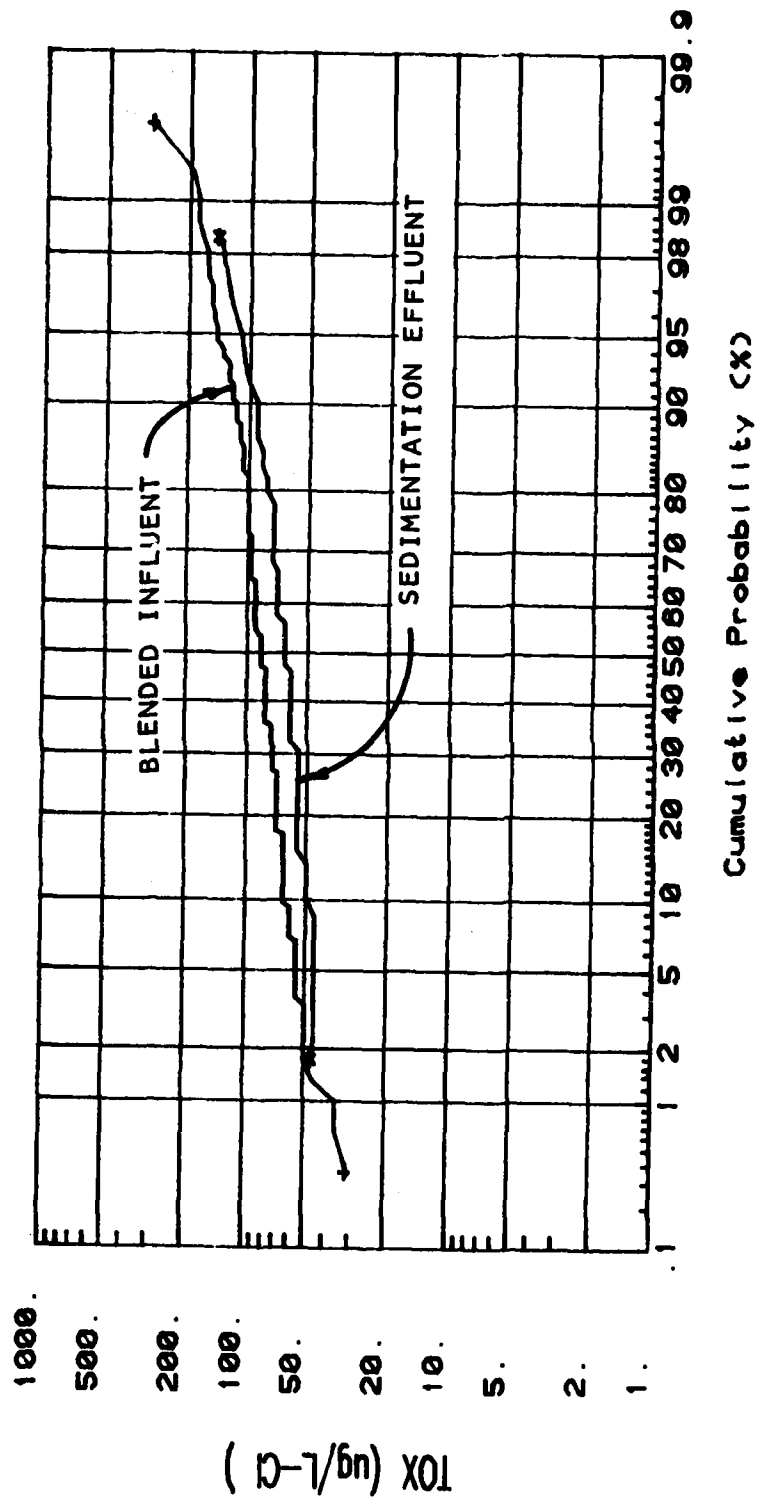
Figures 7.3-23 and 7.3-24 illustrate the fate of the organic compounds targeted for routine quantification at the EEWTP during Phases IA and IB, respectively. The figures indicate the total number of primary compounds detected in more than fifteen percent of the samples at the four indicated sites. The total number of routinely monitored organic compounds (i.e., primary organics) was 151.

Although a greater number of compounds were detected in the blended influent during Phase IB, fewer were observed in the finished water.

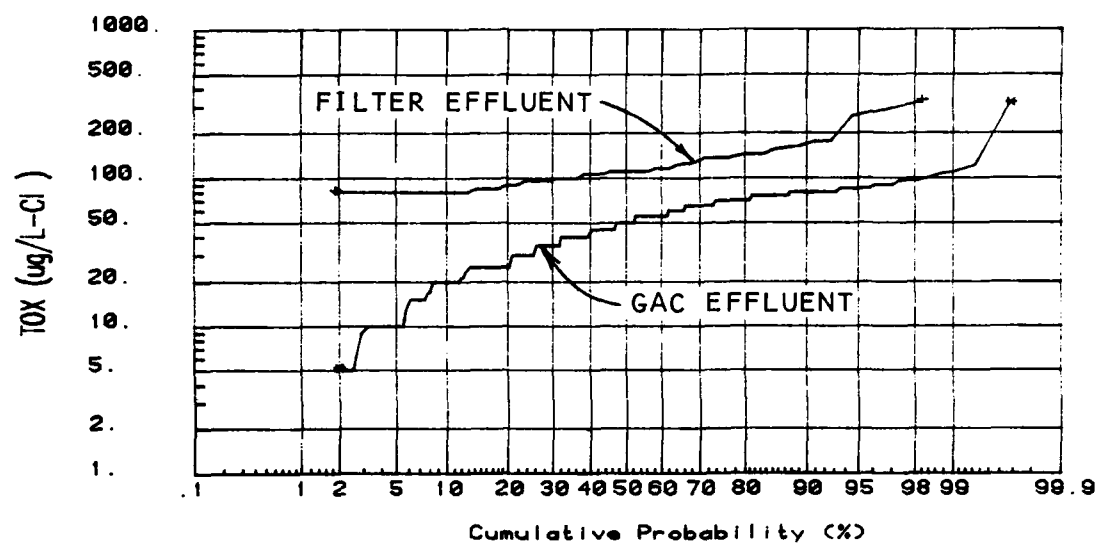
Note that these two figures do not specify the identity or concentrations of the compounds comprising the groups indicated at the four sites. These issues are discussed in the following sections.

Figures 7.3-25 through 7.3-27 present another qualitative indication of the fate of targeted organic compounds at the EEWTP during Phases IA and IB. Figures 7.3-25 and 26 show GC/MS chromatograms for the volatile organic fraction at several sampling sites for a sampling date during Phase IA and IB, respectively. These figures provide a "fingerprint" of the number and relative concentrations

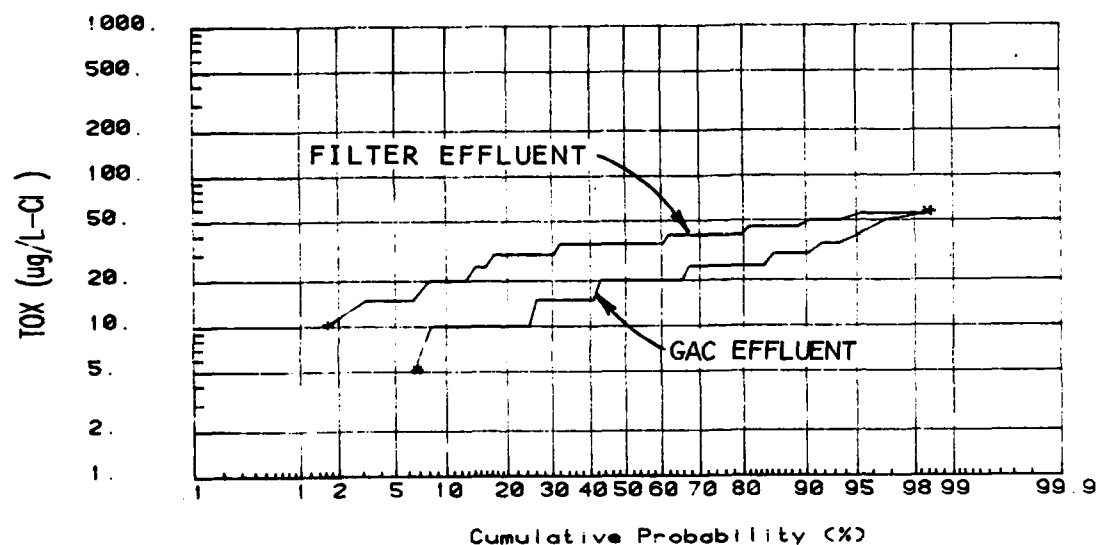




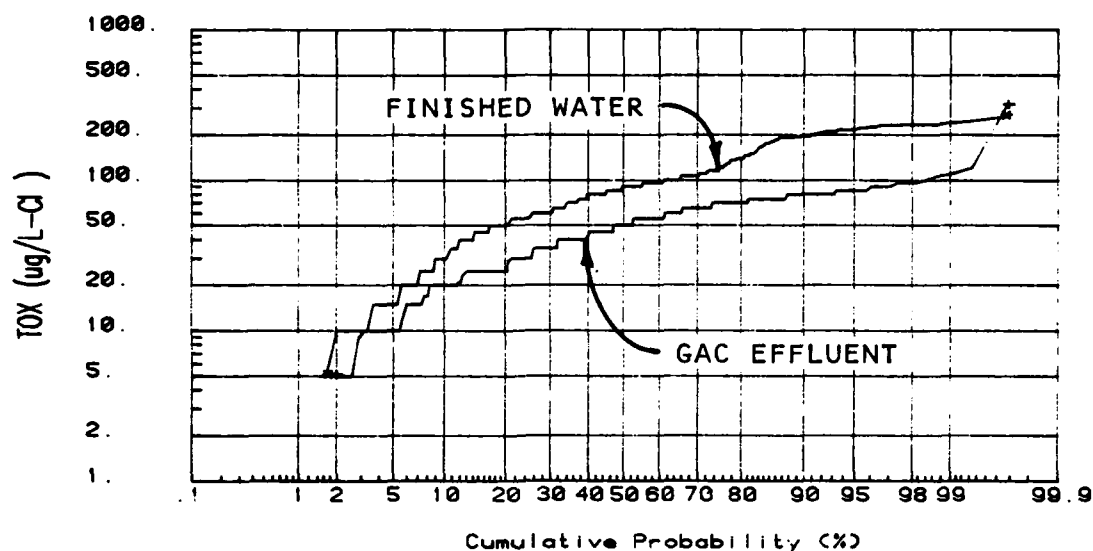
EFFECT OF COAGULATION/SEDIMENTATION  
ON TOX DISTRIBUTION  
FIGURE 7. 3-18



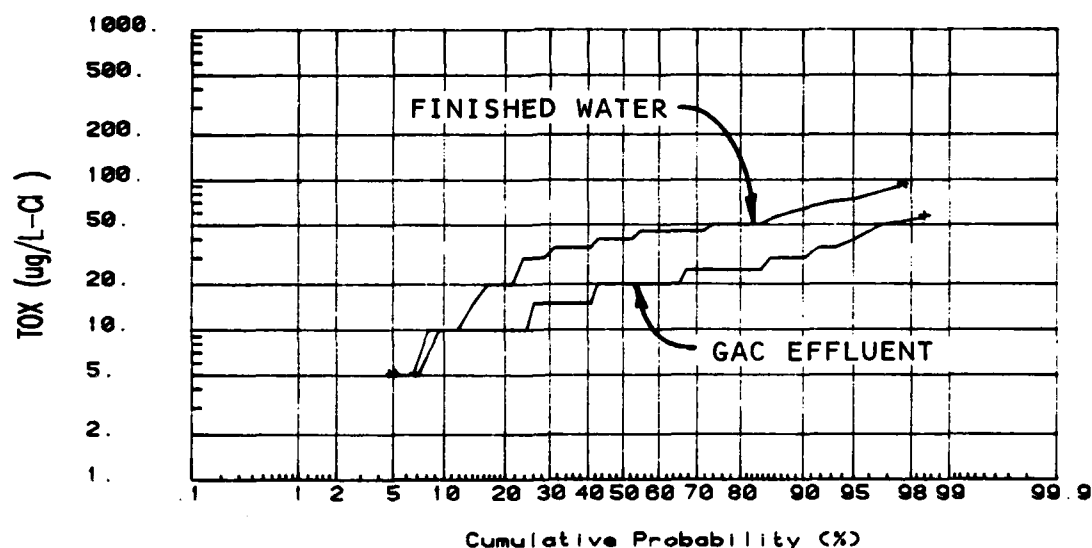
**EFFECT OF GAC ON  
TOX DISTRIBUTION  
(PHASE IA)  
FIGURE 7. 3-19**



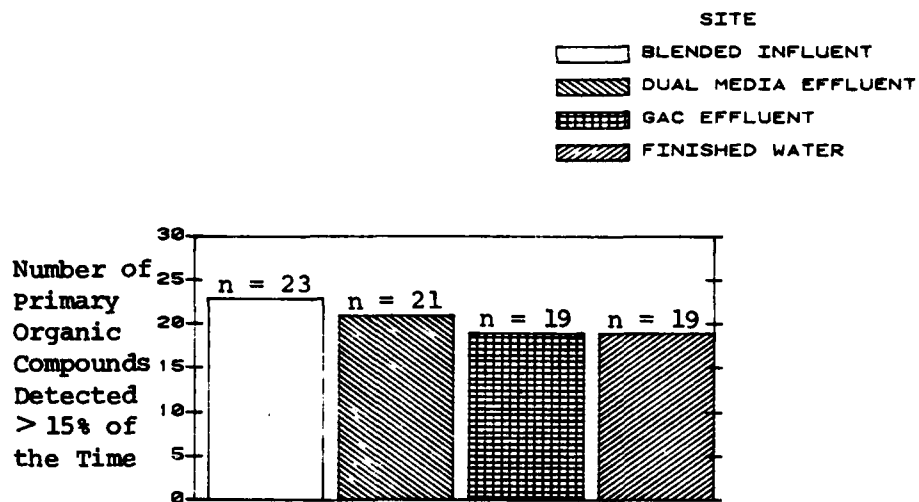
**EFFECT OF GAC ON  
TOX DISTRIBUTION  
(PHASE IB)  
FIGURE 7. 3-20**



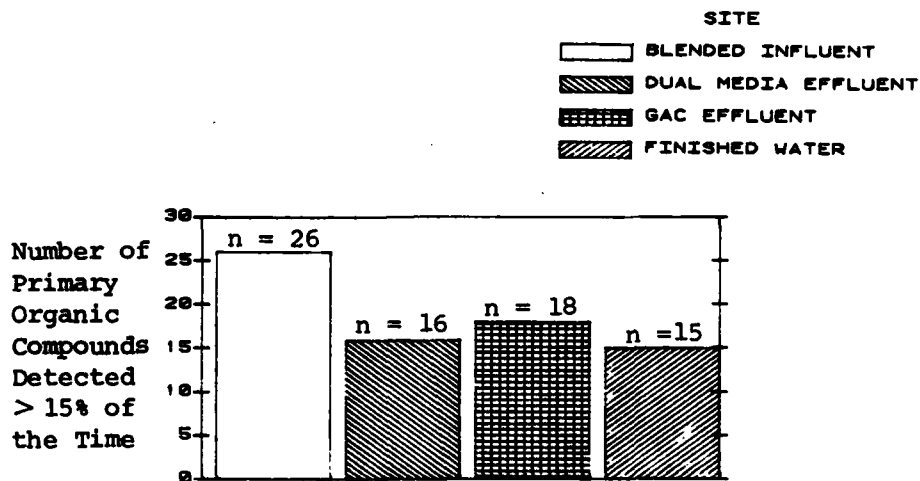
**EFFECT OF CHLORINATION ON  
TOX DISTRIBUTION  
(PHASE IA)  
FIGURE 7. 3-21**



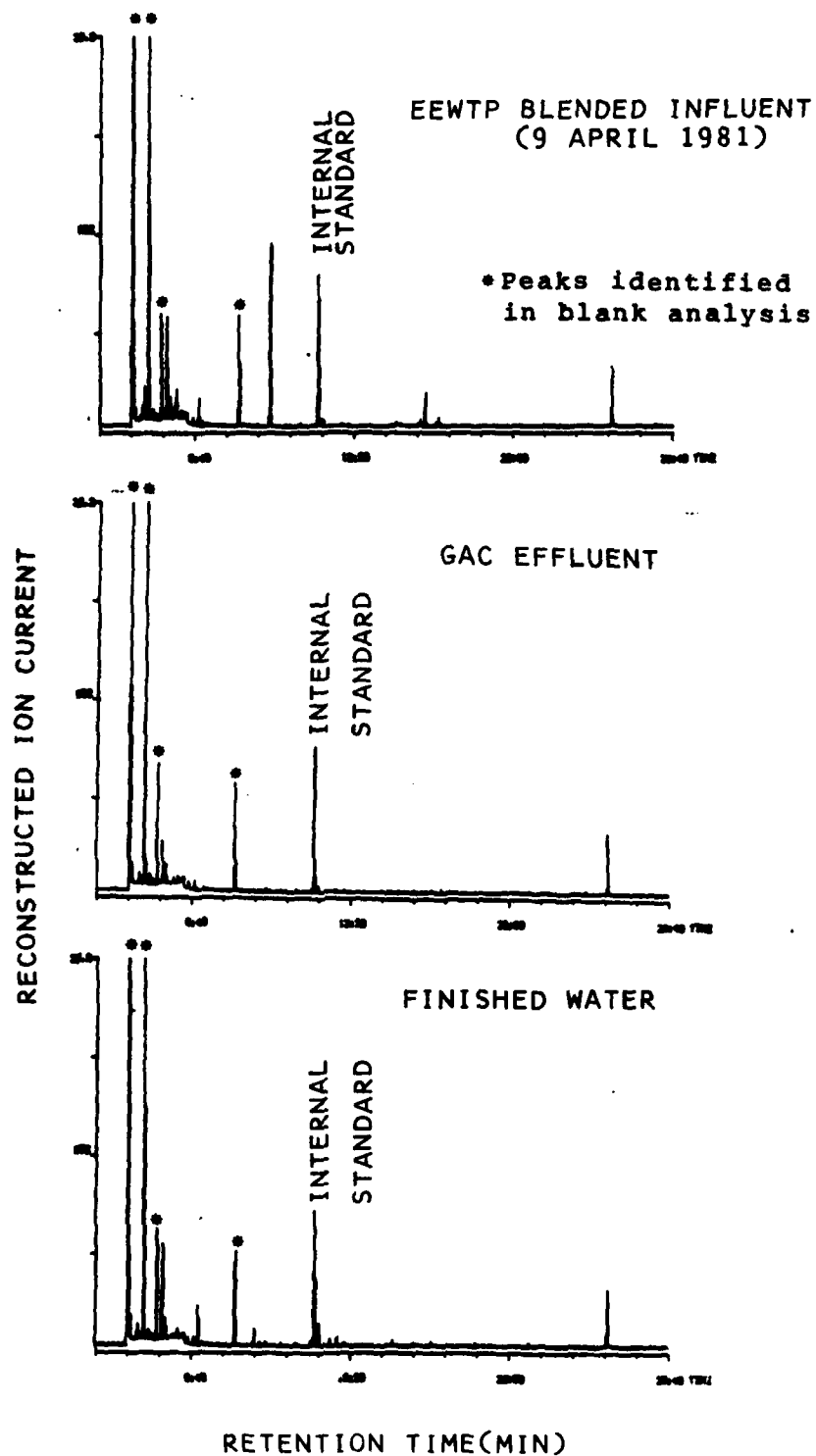
**EFFECT OF CHLORINATION ON  
TOX DISTRIBUTION  
(PHASE IB)  
FIGURE 7. 3-22**



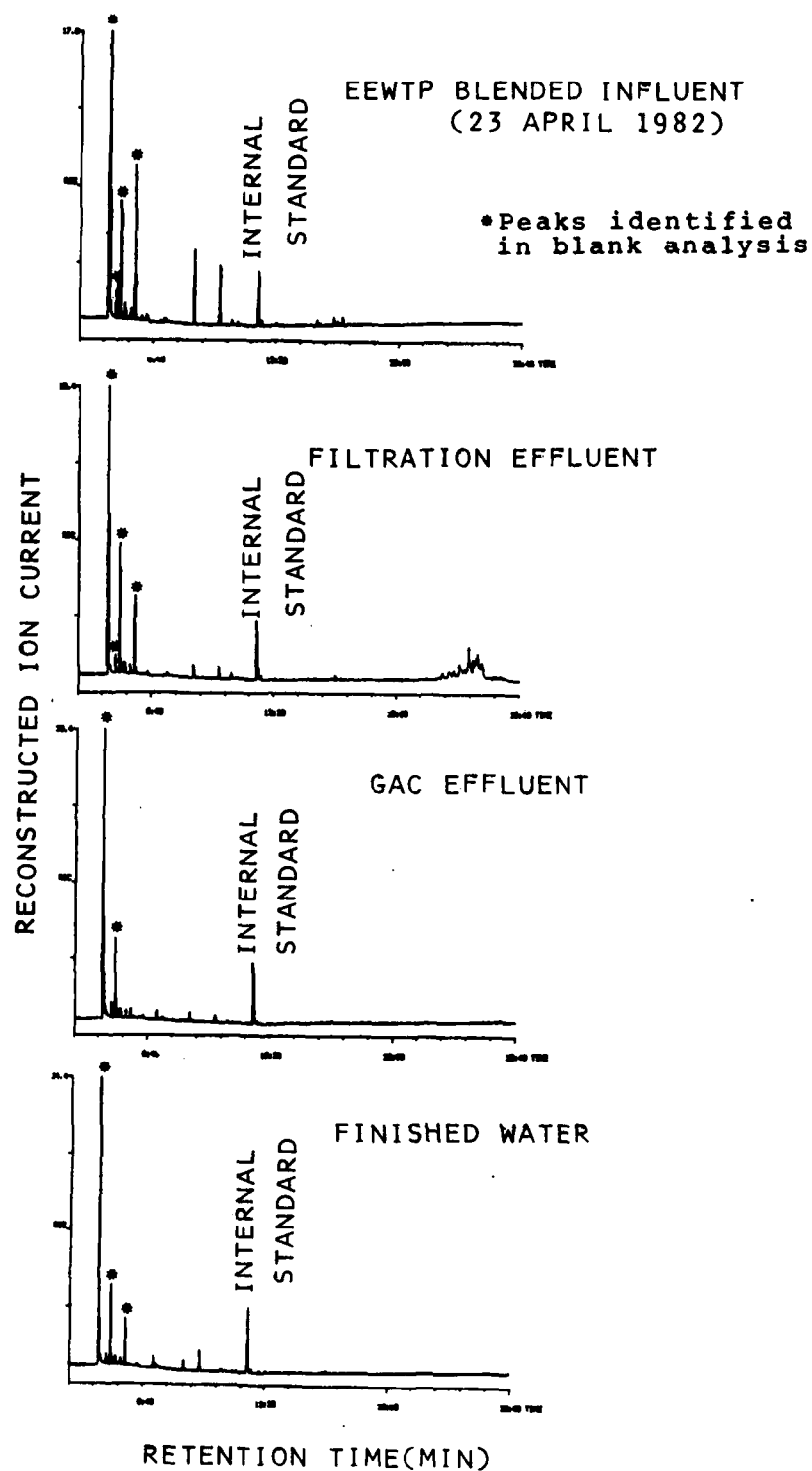
**FATE OF PRIMARY ORGANIC COMPOUNDS**  
**ALL FRACTIONS**  
**(PHASES IA)**  
**FIGURE 7. 3-23**



**FATE OF PRIMARY ORGANIC COMPOUNDS**  
**ALL FRACTIONS**  
**(PHASE IB)**  
**FIGURE 7. 3-24**

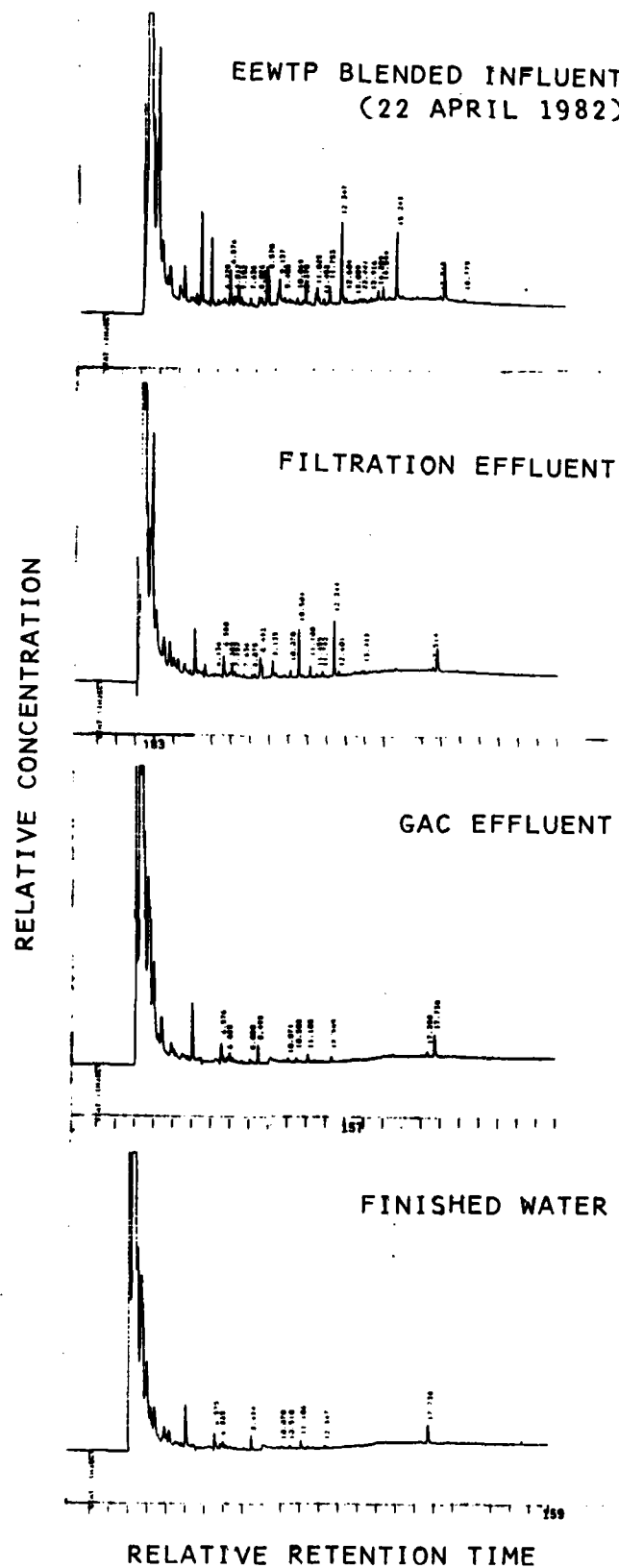


GC/MS CHROMATOGRAMS OF  
VOLATILE ORGANIC FRACTION  
(PHASE 1A)  
FIGURE 7. 3-25



GC/MS CHROMATOGRAMS OF  
VOLATILE ORGANIC FRACTION  
(PHASE IB)

FIGURE 7. 3-26



GC CHROMATOGRAMS OF PESTICIDE/PCB FRACTION  
(PHASE IB)  
FIGURE 7. 3-27

of detected compounds. Note that the relative ion current was proportional to concentration. The disappearance or reduction in height of a given peak indicates complete or partial removal by a specific unit process. These figures show that, for both phases of operation, while GAC adsorption completely or partially removed some compounds found in the blended influent, final disinfection with chlorine formed some new compounds.

Figure 7.3-27 shows a series of GC chromatograms of the pesticide/PCB fraction at several sampling sites for a sampling date during Phase IB. These series of chromatograms illustrate the removals of these more hydrophobic compounds by coagulation/sedimentation/filtration and GAC adsorption.

Tables 7.3-8 and 7.3-9 list those primary compounds detected in more than fifteen percent of samples from among all EEWTP sampling sites during Phases IA and IB, respectively. The tables point out the relative sensitivities of the analytical methods used, as several compounds were analyzed by different methods. Thirty-one different compounds were detected at among all sites during Phase IA and twenty-five different compounds during Phase IB. Of these compounds, four had geometric mean concentrations greater than or equal to 1  $\mu\text{g/L}$  during Phase IA, and three had geometric mean concentrations greater than or equal to 1  $\mu\text{g/L}$  during Phase IB. During Phase IA, only chloroform and tetrachloroethene were detected in the blended influent at  $\geq 1$   $\mu\text{g/L}$ , and only three of the THM species, chloroform, bromodichloromethane, and dibromochloromethane, were detected in the finished water at  $\geq 1$   $\mu\text{g/L}$ .

During Phase IB, only chloroform was detected in the blended influent at  $\geq 1$   $\mu\text{g/L}$ , and the same three THM species were the only compounds detected in the finished water at  $\geq 1$   $\mu\text{g/L}$ .

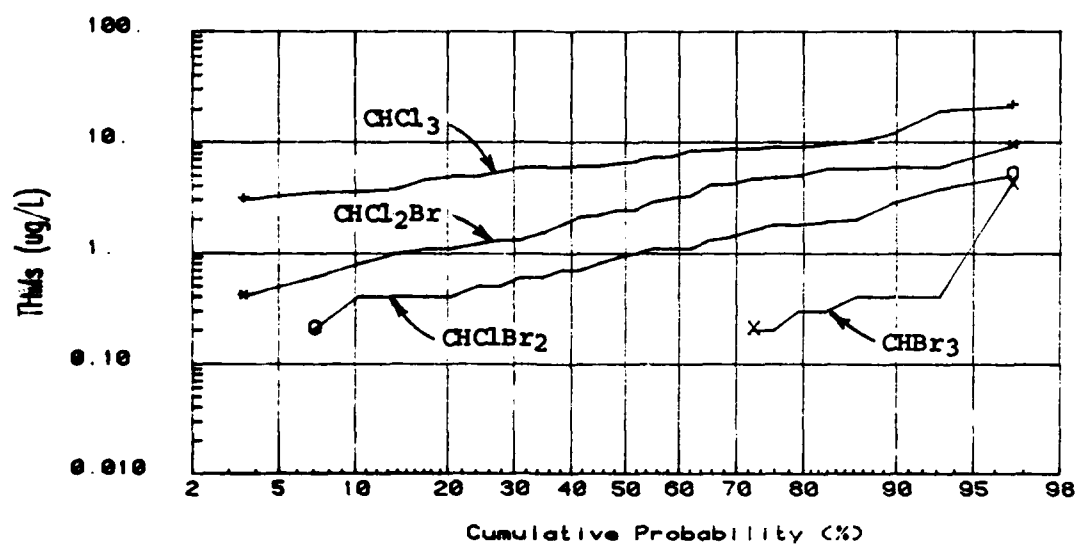
## THMs

The cumulative distribution of the four THM species in the Phase IA filter effluent is shown in Figure 7.3-28. The distributions show that relative concentrations of the THM species decreased with increasing molecular substitution of bromine. The concentrations of all four species reflected low concentrations in the blended influent, with little removal by coagulation/flocculation/filtration. Corresponding distributions for THMs in the Phase IB filter effluent were similar to those for Phase IA.

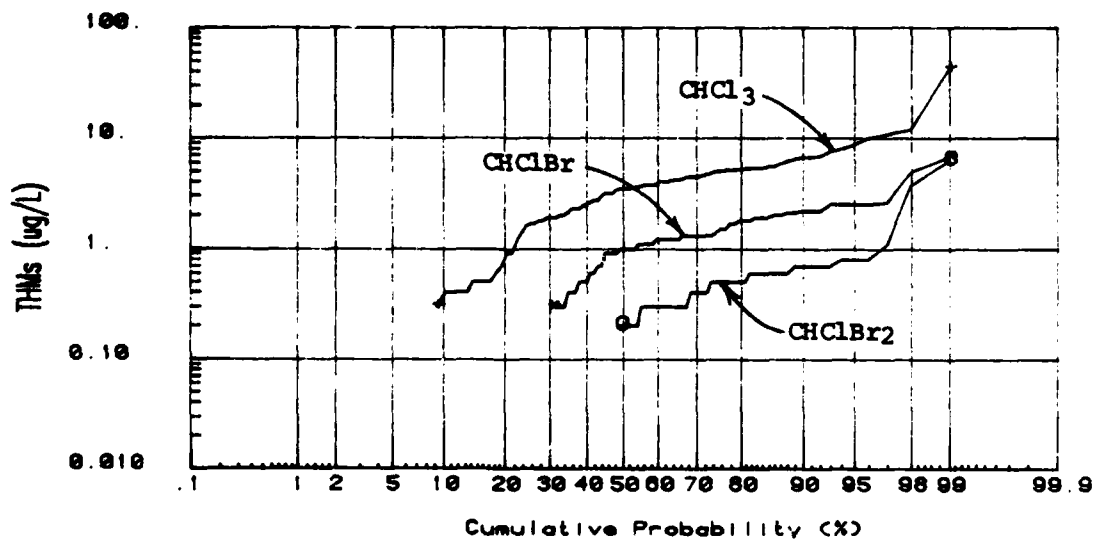
The distribution of THM species in Phase IA GAC effluent is shown in Figure 7.3-29. GAC not only reduced the geometric mean concentrations of THM species, but removed bromoform to below the method detection limit (MDL). The variability of THM concentrations in the GAC effluent, relative to the filter effluent, was greater, as indicated by the increased slope. Again, results for Phase IB were similar.

Figure 7.3-30 shows the effect of final disinfection with chlorine on the distribution of chloroform during Phase IA. The data show that the geometric mean concentration of chloroform, the most predominant THM species, roughly

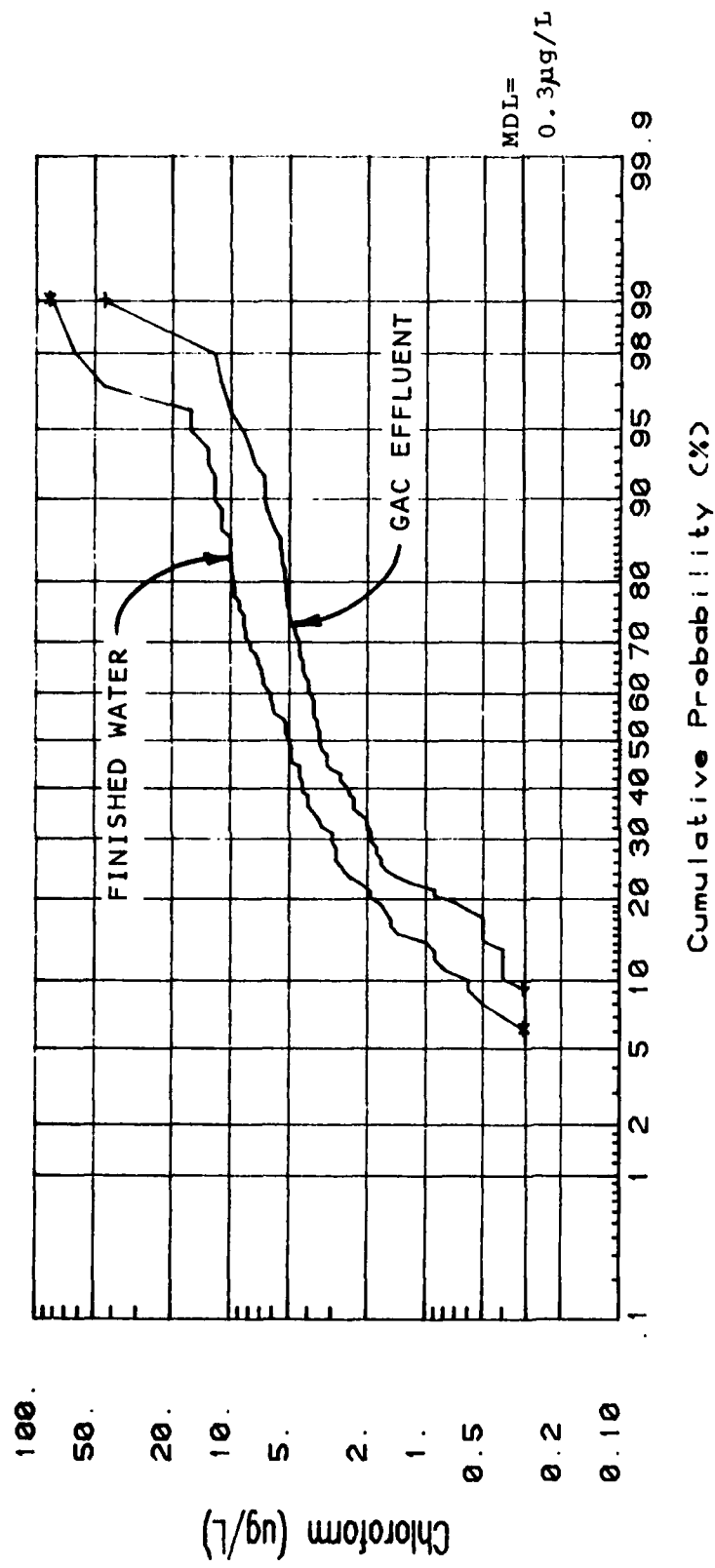




THM SPECIES DISTRIBUTION IN FILTER EFFLUENT  
(PHASE IA)  
FIGURE 7. 3-28



THM SPECIES DISTRIBUTION IN GAC EFFLUENT  
(PHASE IA)  
FIGURE 7. 3-29



EFFECT OF CHLORINATION  
ON CHLOROFORM DISTRIBUTION  
(PHASE 1A)  
FIGURE 7. 3-30

doubled during Phase IA with final disinfection. Again, similar results were observed for Phase IB.

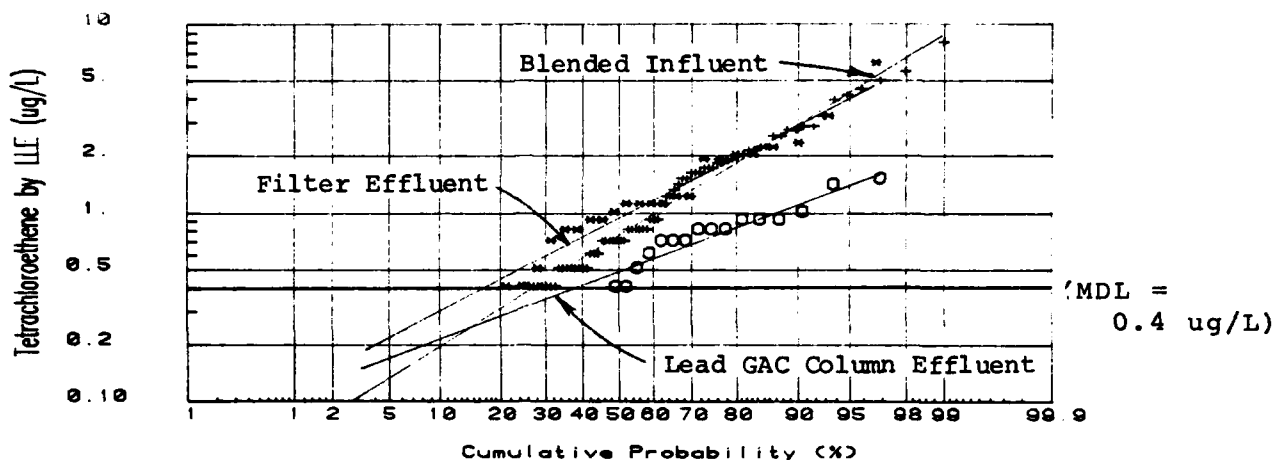
### Selected SOCs

Of the 151 organic compounds targeted for routine quantification, a small number were found in the blended influent, as shown previously in Figures 7.2-4 and 7.2-5 for Phases IA and IB. Three primary organic compounds were selected for illustrative purposes, and are discussed below.

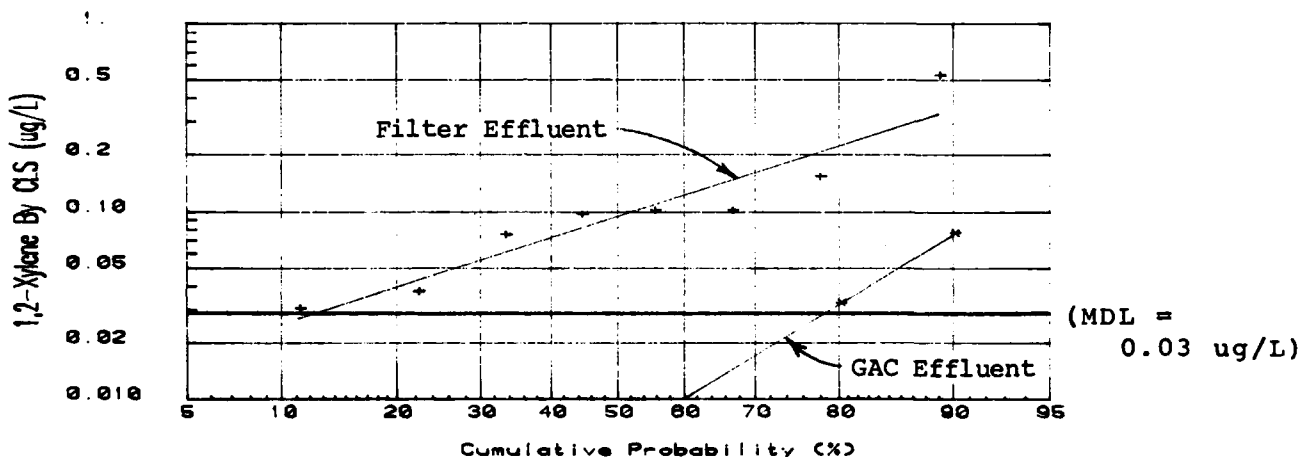
The effect of EEWTP unit processes on tetrachloroethene distribution during Phase IA is shown in Figure 7.3-31. The MDL for tetrachloroethene was 0.4  $\mu\text{g/L}$ . The concentration distributions for the filter effluent and GAC effluent illustrate the removal of tetrachloroethene by GAC. The fractional removal by GAC, indicated by a decrease in the geometric mean, was nearly fifty percent. In addition, the variability of tetrachloroethene concentrations in the lead GAC column effluent was decreased, relative to the blended influent.

Figure 7.3-32 shows the effect of GAC on the distribution of 1,2-xylene during Phase IA. The data show that GAC removed this compound to below the MDL of 0.03  $\mu\text{g/L}$ , as measured by the geometric mean.

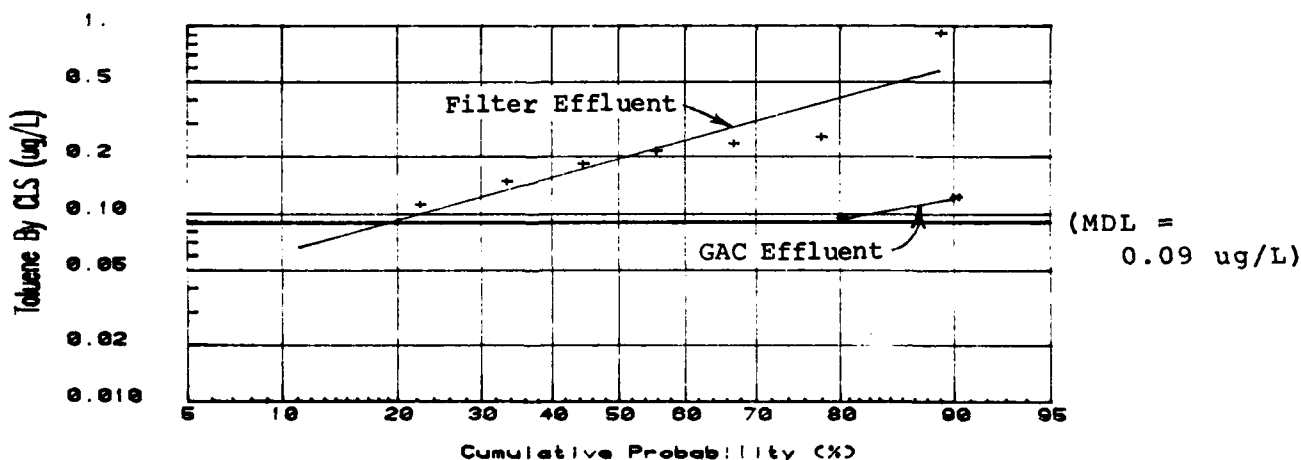
Figure 7.3-33 shows the effect of GAC on the distribution of toluene during Phase IA. The MDL for this compound was 0.09  $\mu\text{g/L}$ . GAC removed this compound to below the MDL, as measured by the geometric mean.



**EFFECT OF EEWTP UNIT PROCESSES ON  
TETRACHLOROETHENE DISTRIBUTION  
(PHASE IA)  
FIGURE 7. 3- 31**



**EFFECT OF GAC ON 1, 2-XYLENE DISTRIBUTION  
(PHASE IA)  
FIGURE 7. 3- 32**



**EFFECT OF GAC ON TOLUENE DISTRIBUTION  
(PHASE IA)  
FIGURE 7. 3- 33**

TABLE 7.3-8  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Chloroform by LLE					
Number Det'd/Number	90/93	26/30	28/28	90/97	95/98
Geometric Mean/Spread Factor	1.54/1.95	1.34/2.54	6.90/1.57	2.31/3.14	4.06/3.27
Median/90% Value	1.5/3.1	1.6/4.2	6.5/12.0	3.5/6.7	5.0/11.0
Chloroform by VOA					
Number Det'd/Number	19/19	NMa	9/9	20/20	18/18
Geometric Mean/Spread Factor	1.50/1.48		5.00/2.44	2.50/2.69	6.36/2.07
Median/90% Value	1.5/2.5		7.9/13.0	3.5/5.8	7.7/13.0
Bromodichloromethane by LLE					
Number Det'd/Number	90/93	27/30	28/28	83/97	98/99
Geometric Mean/Spread Factor	0.27/1.74	0.28/1.20	2.34/2.19	0.64/3.03	2.17/3.06
Median/90% Value	<0.3/0.6	<0.3/0.3	2.4/6.0	1.0/2.2	2.5/8.7
Bromodichloromethane by VOA					
Number Det'd/Number	17/19	NM	8.9	17.20	18.18
Geometric Mean/Spread Factor	0.20/1.37		1.45/2.89	0.61/2.79	4.60/2.36
Median/90% Value	0.2/0.3		1.9/4.3	0.8/1.5	3.5/15.0
Bromodichloromethane by CLS					
Number Det'd/Number	9/9	NM	7/8	9/9	9/9
Geometric Mean/Spread Factor	0.2278/2.68		1.3031/4.73	0.7075/1.71	1.8110/1.69
Median/90% Value	0.220/2.000		1.700/9.900	0.730/2.200	1.900/3.600
Dibromochloromethane by LLE					
Number Det'd/Number	60/93	21/30	27/28	65/97	94/99
Geometric Mean/Spread Factor	0.16/1.39	0.11/1.78	0.90/2.27	0.21/2.86	1.35/2.99
Median/90% Value	NQ/0.2	NQ/0.2	0.9/2.8	0.2/0.7	1.6/5.3

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Dibromochloromethane by VOA					
Number Det'd/Number	7/19	NM	8/9	11/20	17/18
Geometric Mean/Spread Factor	NC <sup>b</sup>		0.32/1.64	NC <sup>c</sup>	2.22/3.44
Median/90% Value	<0.1/<0.4		<0.4/0.8	<0.4/<0.4	2.7/9.9
Dibromochloromethane by CLS					
Number Det'd/Number	9/9	NM	8/8	9/9	9/9
Geometric Mean/Spread Factor	0.1061/1.62		1.447/2.19	0.1824/2.78	2.1327/1.88
Median/90% Value	0.100/0.260		0.720/3.800	0.201/1.000	1.700/9.500
Bromoform by LLE					
Number Det'd/Number	11/93	4/30	10/28	13/97	57/99
Geometric Mean/Spread Factor	NC	NC	0.08/4.11	NC	0.22/3.49
Median/90% Value	<0.1/<0.2	<0.1/<0.2	<0.1/<0.4	<0.1/0.4	0.2/1.1
Bromoform by VOA					
Number Det'd/Number	11/19	NM	0/9	2/20	12/18
Geometric Mean/Spread Factor	NC		NC	NC	0.58/1.85
Median/90% Value	<0.1/<0.1		<0.1/<0.1	<0.1/<0.1	<0.6/1.8
Bromoform by CLS					
Number Det'd/Number	4/9	NM	8/8	3/9	9/9
Geometric Mean/Spread Factor	NC		0.0696/5.52	<0.005/0.048	0.3399/3.43
Median/90% Value	<0.005/<0.040		0.041/0.930	<0.005/0.048	0.350/2.200
Carbon Tetrachloride by LLE					
Number Det'd/Number	44/60	46/69	47/58	45/57	49/99
Geometric Mean/Spread Factor	NC	NC	NC	NC	NC
Median/90% Value	<0.2/<0.2	<0.2/<0.2	<0.2/0.2	<0.2/0.2	<0.2/<0.2

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Trichlorofluoromethane by VOA					
Number Det'd/Number	8/19	NM	1/9	7/20	8/18
Geometric Mean/Spread Factor	0.04/20.42		NC	0.14/6.56	0.26/2.89
Median/90% Value	<0.1/5.1		<0.1/<0.4	<0.1/0.9	<0.1/1.3
1,1,1-Trichloroethane by VOA					
Number Det'd/Number	15/19	NM	5/9	10/20	10/18
Geometric Mean/Spread Factor	0.15/1.74		NC	NC	NC
Median/90% Value	<0.2/0.3		<0.2/<0.2	<0.1/<0.2	<0.2/<0.2
1,1,2-Trichloroethane by CLS					
Number Det'd/Number	4/9	NM	3/8	2/9	1/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/<0.07		<0.001/<0.07	<0.001/<0.07	<0.001/<0.07
1,2-Dichloropropane by CLS					
Number Det'd/Number	8/9	NM	6/8	4/9	3/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.08/<0.08		<0.08/<0.08	<0.001/<0.08	<0.001/<0.08
Tetrachloroethene by LLE					
Number Det'd/Number	91/93	29/30	28/28	44/97	50/99
Geometric Mean/Spread Factor	0.78/2.67	0.99/2.08	0.92/2.33	NC	NC
Median/90% Value	0.7/2.7	1.1/2.1	1.0/2.3	<0.1/<0.4	<0.4/<0.4
Tetrachloroethene by VOA					
Number Det'd/Number	15/19	NM	9/9	8/20	6/18
Geometric Mean/Spread Factor	0.74/2.48		0.55/1.93	NC	NC
Median/90% Value	0.7/2.2		0.5/1.5	<0.2/<0.5	<0.2/<0.5

TABLE 7.3-8 (Continued)  
 SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
 DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
 PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
<b>Tetrachloroethene by CLS</b>					
Number Det'd/Number	9/9	NM	7/8	3/9	3/9
Geometric Mean/Spread Factor	1.9204/2.45		0.4778/5.90	0.0094/8.87	0.0084/11.78
Median/90% Value	1.700/7.00		0.880/2.400	<0.01/0.150	<0.01/0.230
<b>Trichloroethene by LLE</b>					
Number Det'd/Number	32/93	18/30	15/28	14/97	12/99
Geometric Mean/Spread Factor	NC	0.21/2.11	0.12/3.12	NC	NC
Median/90% Value	<0.1/<0.3	<0.3/0.5	<0.3/0.6	<0.1/<0.3	<0.1/<0.3
<b>Trichloroethene by VOA</b>					
Number Det'd/Number	7/19	NM	3/9	4/20	3/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/<0.7		<0.1/<0.7	<0.1/<0.7	<0.1/<0.7
<b>Trichloroethene by CLS</b>					
Number Det'd/Number	7/9	NM	4/8	0/9	0/9
Geometric Mean/Spread Factor	0.1483/2.60		0.1204/1.26	NC	NC
Median/90% Value	0.140/0.630		0.180/0.180	<0.001/<0.001	<0.001/<0.001
<b>Ethylbenzene by CLS</b>					
Number Det'd/Number	7/9	NM	8/8	7/9	6/9
Geometric Mean/Spread Factor	0.0224/2.99		0.0302/1.85	0.0215/1.52	0.0137/2.88
Median/90% Value	0.020/0.120		0.028/0.0097	0.021/0.056	<0.020/0.063
<b>Ethylbenzene by CLS</b>					
Number Det'd/Number	7/9	NM	6/8	6/9	7/9
Geometric Mean/Spread Factor	0.0350/3.38		0.0612/2.90	0.0175/3.13	0.0276/2.27
Median/90% Value	<0.040/0.200		0.054/0.250	<0.040/0.110	<0.040/0.130



TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Ethylbenzene by VOA					
Number Det'd/Number	0/19	NM	0/9	1/20	5/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/<0.1		<0.1/<0.1	<0.1/<0.1	<0.1/<0.1
Propylbenzene by CLS					
Number Det'd/Number	8/9	NM	8/8	3/9	4/9
Geometric Mean/Spread Factor	0.0145/2.35		0.0217/2.77	NC	0.0030/4.72
Median/90% Value	0.015/0.067		0.021/0.130	<0.001/<0.010	<0.001/0.052
Toluene by VOA					
Number Det'd/Number	3/19	NM	0/9	4/20	3/18
Geometric Mean/Spread Factor	0.01/11.97		NC	0.01/19.21	0.01/13.08
Median/90% Value	<0.1/0.4		<0.1/<0.1	<0.1/0.7	<0.1/0.6
Toluene by CLS					
Number Det'd/Number	6/9	NM	7/8	2/9	4/9
Geometric Mean/Spread Factor	0.1179/2.36		0.1930/2.08	0.0730/1.32	0.0828/2.05
Median/90% Value	0.110/0.600		0.180/0.900	<0.020/0.120	<0.020/0.270
1,2-Xylene by VOA					
Number Det'd/Number	0/19	NM	0/9	1/20	6/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/<0.1		<0.1/<0.1	<0.1/<0.1	<0.1/0.1
1,2-Xylene by CLS					
Number Det'd/Number	7/9	NM	8/8	3/9	5/9
Geometric Mean/Spread Factor	0.0383/3.49		0.0941/2.27	0.0153/2.40	0.0283/2.52
Median/90% Value	0.045/0.270		0.095/0.520	<0.005/0.076	<0.030/0.120

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,3-Xylene/1,4-Xylene by VOA					
Number Det'd/Number	2/19	NM	0/9	2/20	6/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/<0.4		<0.1/<0.1	<0.1/<0.1	<0.1/<0.4
1,3-Xylene/1,4-Xylene by CLS					
Number Det'd/Number	7/9	NM	6/8	3/9	5/9
Geometric Mean/Spread Factor	0.0497/2.40		0.0638/2.90	NC	0.0370/2.74
Median/90% Value	0.047/0.300		0.068/0.260	<0.005/0.043	<0.040/0.190
Di-n-Butylphthalate by Base/Neutral LLE					
Number Det'd/Number	1/16	NM	2/5	0/16	0/15
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.5/<0.5		<0.5/<9.0	<0.5/<0.5	<0.5/<0.5
Phenol by Acid (w/methylatton) VOA					
Number Det'd/Number	1/4	NM	1/4	0/3	0/3
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<1.0/<8.0		<1.0/<8.0	<1.0/<1.0	<1.0/<1.0
Naphthalene by CLS					
Number Det'd/Number	5/9	NM	5/8	2/9	2/9
Geometric Mean/Spread Factor	NC		0.049/3.06	NC	0.0129/4.81
Median/90% Value	<0.040/0.080		<0.040/0.200	<0.010/0.118	<0.040/0.158
Bromobenzene by CLS					
Number Det'd/Number	1/9	NM	1/8	2/9	2/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/<0.02		<0.001/<0.02	<0.001/<0.02	<0.001/<0.02

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
4-Chloro-1-methylbenzene by CLS					
Number Det'd/Number	3/9	NM	1/8	0/9	0/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/0.093		<0.001/0.091	<0.001/<0.001	<0.001/<0.001
1,2-Dichlorobenzene by VOA					
Number Det'd/Number	8/19	NM	1/9	1/20	0/18
Geometric Mean/Spread Factor	0.08/2.65		NC	NC	NC
Median/90% Value	<0.1/0.3		<0.1/<0.2	<0.1/<0.1	<0.1/<0.1
1,2-Dichlorobenzene by CLS					
Number Det'd/Number	9/9	NM	8/8	0/9	0/9
Geometric Mean/Spread Factor	0.0486/1.82		0.0328/1.85	NC	NC
Median/90% Value	0.048/0.140		0.029/0.120	<0.001/<0.001	<0.001/<0.001
1,3-Dichlorobenzene by VOA					
Number Det'd/Number	8/19	NM	1/9	1/20	0/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/<0.2		<0.1/<0.2	<0.1/<0.1	<0.1/<0.1
1,3-Dichlorobenzene by CLS					
Number Det'd/Number	9/9	NM	8/8	3/9	4/9
Geometric Mean/Spread Factor	0.0752/2.48		0.0709/2.50	NC	NC
Median/90% Value	0.065/0.370		0.064/0.370	<0.0001/<0.02	<0.0001/<0.02
1,4-Dichlorobenzene by VOA					
Number Det'd/Number	7/19	NM	1/9	1/20	0/18
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/0.2		<0.1/<0.2	<0.1/<0.1	<0.1/<0.1

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IA

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,4-Dichlorobenzene by CLS					
Number Det'd/Number	8/9	NM	8/8	5/9	4/9
Geometric Mean/Spread Factor	0.1057/2.89		0.1113/2.51	NC	NC
Median/90% Value	0.090/0.710		0.056/0.710	<0.02/<0.02	<0.0001/<0.02
1,2,3-Trichlorobenzene by CLS					
Number Det'd/Number	6/9	NM	6/8	3/9	2/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.03/0.061		<0.03/<0.03	<0.001/0.03	<0.001/<0.03
1,2,4-Trichlorobenzene by CLS					
Number Det'd/Number	7/9	NM	7/8	3/9	4/9
Geometric Mean/Spread Factor	0.0199/1.42		0.0176/1.63	NC	NC
Median/90% Value	<0.020/0.031		<0.020/0.038	<0.001/<0.020	<0.001/<0.020
1,3,5-Trichlorobenzene by CLS					
Number Det'd/Number	2/9	NM	0/8	0/9	0/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/<0.02		<0.001/<0.001	<0.001/<0.001	<0.001/<0.001
Tetrahydrofuran by VOA					
Number Det'd/Number	4/19	NM	0/9	4/20	3/18
Geometric Mean/Spread Factor	0.02/11.88		NC	0.03/12.68	0.02/9.73
Median/90% Value	<0.1/1.1		<0.1/<0.1	<0.1/1.0	<0.1/0.8

TABLE 7.3-8 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE 1A

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Acetone by VOA					
Number Det'd/Number	0.19	NM	2/9	1/18	2/18
Geometric Mean/Spread Factor	NC		0.13/6.12	NC	NC
Median/90% Value	<0.5/<0.5		<0.5/2.9	<0.5/<0.5	<0.5/9.6
Geosmin by CLS					
Number Det'd/Number	5/9	NM	7/8	1/9	2/9
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.05/<0.05		<0.05/<0.05	<0.0005/<0.05	<0.0005/<0.05

a. NM = Not Measured.

b. NC = Not Calculated (i.e., less than fifteen percent of samples were  $\geq$  MDL).

TABLE 7.3-9  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Chloroform by LLE					
Number Det'd/Number	52/52	55/61	56/61	38/57	36/41
Geometric Mean/Spread Factor	1.68/1.44	1.00/1.78	0.91/1.76	0.32/3.79	1.47/3.22
Median/90% Value	1.6/2.6	1.2/1.6	1.1/1.4	0.3/2.4	2.1/5.2
Chloroform by VOA					
Number Det'd/Number	6/6	NM <sup>a</sup>	6/8	6/8	8/8
Geometric Mean/Spread Factor	1.41/1.79		0.22/3.07	0.20/3.21	1.08/2.55
Median/90% Value	1.3/4.5		<0.2/0.9	<0.2/1.4	1.3/3.2
Bromodichloromethane by LLE					
Number Det'd/Number	52/52	53/61	54/61	11/57	40/41
Geometric Mean/Spread Factor	0.29/1.96	0.24/1.33	NC <sup>b</sup>	NC	1.56/3.11
Median/90% Value	0.3/0.5	<0.3/0.3	<0.3/0.3	<0.1/1.2	2.5/3.6
Bromodichloromethane by VOA					
Number Det'd/Number	3/6	NM	1/8	1/8	7/8
Geometric Mean/Spread Factor	0.10/4.12		NC	NC	1.19/2.56
Median/90% Value	<0.1/1.1		<0.1/<0.2	<0.1/0.6	1.7/2.6
Bromodichloromethane by CLS					
Number Det'd/Number	6/6	NM	7/7	4/8	6/6
Geometric Mean/Spread Factor	0.1277/2.09		0.1388/1.77	0.0328/9.58	0.6668/2.37
Median/90% Value	0.120/0.490		0.120/0.270	<0.001/1.90	0.510/2.800
Dibromochloromethane by LLE					
Number Det'd/Number	46/52	44/61	44/61	7/57	40/41
Geometric Mean/Spread Factor	0.09/3.03	0.17/1.22	NC	NC	2.06/3.55
Median/90% Value	<0.2/0.2	<0.2/0.2	<0.2/0.2	<0.1/0.3	3.0/5.5

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OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
POTOMAC ESTUARY E. (U) MONTGOMERY (JAMES M) CONSULTING  
ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

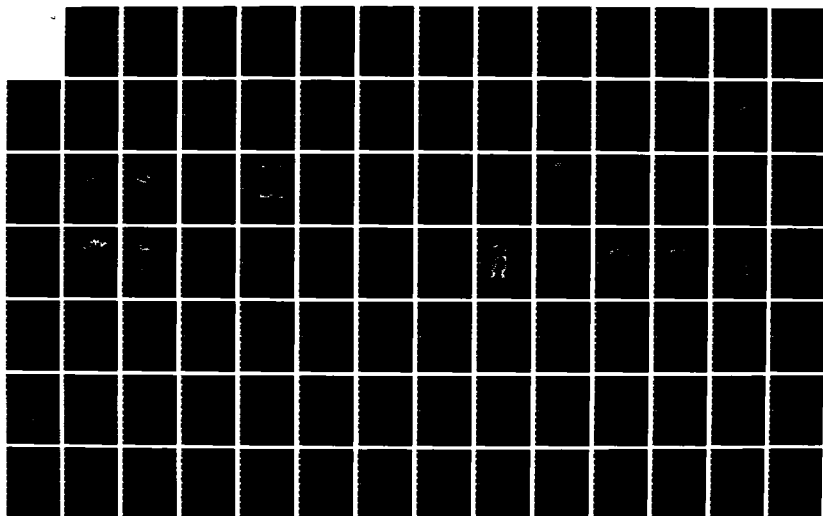
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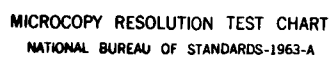
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TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Dibromochloromethane by VOA					
Number Det'd/Number	0/6	NM	0/8	1/8	7/8
Geometric Mean/Spread Factor	NC		NC	NC	1.30/2.43
Median/90% Value	<0.1/<0.1		<0.1/<0.1	<0.1/<0.4	1.8/3.0
Dibromochloromethane by CLS					
Number Det'd/Number	6/6	NM	7/7	4.8	6/6
Geometric Mean/Spread Factor	0.0552/3.98		0.0328/2.31	0.0140/6.89	1.7877/4.45
Median/90% Value	<0.050/0.450		<0.050/0.110	<0.001/0.0300	2.40/15.00
Bromoform by LLE					
Number Det'd/Number	3/52	0/61	0/61	0/57	29/41
Geometric Mean/Spread Factor	NC		NC	NC	0.64/4.06
Median/90% Value	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	1.1/2.1
Bromoform by VOA					
Number Det'd/Number	0/6	NM	0/8	0/8	5/8
Geometric Mean/Spread Factor	NC		NC	NC	0.62/1.36
Median/90% Value	<0.1/<0.1		<0.1/<0.1	<0.1/<0.1	<0.6/0.9
Bromoform by CLS					
Number Det'd/Number	3/6	NM	2/7	1/8	6/6
Geometric Mean/Spread Factor	NC		NC	NC	0.2623/6.94
Median/90% Value	<0.005/0.062		<0.005/<0.040	<0.005/<0.040	<0.1/<0.1
Carbon Tetrachloride by LLE					
Number Det'd/Number	3/52	2/62	2/61	15/57	3/41
Geometric Mean/Spread Factor	NC	NC	NC	NC	NC
Median/90% Value	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.2	<0.1/<0.1

TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,1,2,2-Tetrachloroethane by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/6 NC <0.001/<0.05	NM	1/7 NC <0.001/<0.05	2/8 NC <0.001/<0.05	2/6 NC <0.001/<0.05
1,1,1-Trichloroethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/6 0.15/1.78 <0.2/0.4	NM	1/8 NC <0.1/<0.2	1/8 NC <0.1/0.5	0/8 NC <0.1/<0.1
1,1,2-Trichloroethane by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/6 NC <0.001/<0.07	NM	2/7 NC <0.001/<0.07	2/8 NC <0.001/<0.07	0/6 NC <0.001/<0.001
1,2-Dichloropropane by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/6 NC <0.08/<0.08	NM	3/7 NC <0.001/0.270	0/8 NC <0.001/<0.001	0/6 NC <0.001/<0.001
Tetrachloroethene by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	52/52 0.87/1.86 0.8/1.8	60/61 0.39/1.92 0.4/0.9	60/61 0.22/2.38 <0.4/0.6	33/57 0.29/1.46 <0.4/0.4	14/41 NC <0.1/<0.4
Tetrachloroethene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/6 0.82/2.36 0.6/4.2	NM	2/8 NC <0.2/1.1	1/8 NC <0.2/<0.5	0/8 NC <0.2/<0.2

TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
<b>Tetrachloroethene by CLS</b>					
Number Det'd/Number	6/6	NM	7/7	8/8	7/6
Geometric Mean/Spread Factor	0.7907/2.39		0.2341/2.09	0.1557/1.83	0.0241/5.14
Median/90% Value	0.510/5.000		0.170/1.000	0.110/0.480	<0.010/0.160
<b>Trichloroethene by LLE</b>					
Number Det'd/Number	28/52	3/61	2/61	15/57	2/41
Geometric Mean/Spread Factor	NC	NC	NC	0.15/2.96	NC
Median/90% Value	<0.3/<0.3	<0.1/<0.1	<0.1/<0.1	<0.1/0.6	<0.1/<0.1
<b>Trichloroethene by CLS</b>					
Number Det'd/Number	2/6	NM	2/7	4/8	0/6
Geometric Mean/Spread Factor	NC		NC	0.0946/1.61	NC
Median/90% Value	<0.001/0.200		<0.001/0.078	<0.001/0.217	<0.001/<0.001
<b>Trichloroethene by VOA</b>					
Number Det'd/Number	0.6	NM	0/8	2/8	0/8
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.01/<0.01		<0.1/<0.1	<0.1/<0.7	<0.1/<0.7
<b>Ethylbenzene by CLS</b>					
Number Det'd/Number	2/6	NM	5/7	7/8	4/6
Geometric Mean/Spread Factor	NC		NC	NC	0.0185/1.23
Median/90% Value	<0.005/<0.020		<0.020/0.025	<0.020/0.048	<0.020/0.025
<b>Ethylbenzene by CLS</b>					
Number Det'd/Number	3/6	NM	5/7	7/8	6/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.005/<0.04		<0.04/<0.04	<0.04/<0.04	<0.04/<0.04

TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Propylbenzene by CLS					
Number Det'd/Number	2/6	NM	4/7	0/8	0/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/<0.01		<0.01/<0.01	<0.001/<0.001	<0.001/<0.001
Toluene by VOA					
Number Det'd/Number	1/6	NM	0/8	0/8	0/8
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.1/0.2		<0.1/<0.1	<0.1/<0.1	<0.1/<0.1
Toluene by CLS					
Number Det'd/Number	4/6	NM	6/7	6/8	3/6
Geometric Mean/Spread Factor	0.096/2.44		0.0822/2.18	0.0890/1.94	0.0791/1.37
Median/90% Value	<0.090/0.350		<0.090/0.220	<0.090/0.290	<0.020/0.130
1,2-Xylene by CLS					
Number Det'd/Number	4/6	NM	6/7	6/8	6/6
Geometric Mean/Spread Factor	NC		0.0209/1.95	NC	0.0289/1.08
Median/90% Value	<0.030/<0.030		<0.030/0.062	<0.030/<0.030	<0.030/0.033
1,3-Xylene/1,4-Xylene by CLS					
Number Det'd/Number	3/6	NM	5/7	6/8	6/6
Geometric Mean/Spread Factor	NC		NC	NC	0.0375/1.17
Median/90% Value	<0.005/<0.040		<0.040/0.045	<0.040/<0.040	<0.040/0.048
Napthalene by CLS					
Number Det'd/Number	0/6	NM	0/7	1/8	1/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.01/<0.01		<0.01/<0.01	<0.01/<0.04	<0.04/<0.04

TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,2-Dichlorobenzene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/6 NC <0.1/<0.2	NM	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1
1,2-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/6 0.0362/1.77 0.036/0.095	NM	4/7 NC <0.02/<0.02	1/8 NC <0.0001/<0.02	1/6 NC <0.0001/<0.02
1,3-Dichlorobenzene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/6 NC <0.1/<0.2	NM	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1
1,3-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/6 0.0383/2.19 0.028/0.140	NM	4/7 0.0103/3.63 <0.01/0.072	3/8 NC <0.0001/<0.02	1/6 NC <0.0001/<0.02
1,4-Dichlorobenzene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/6 NC <0.1/<0.2	NM	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1	0/8 NC <0.1/<0.1
1,4-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/6 0.0258/1.50 0.024/0.038	NM	4/7 NC <0.02/0.024	3/8 NC <0.0001/<0.02	1/6 NC <0.0001/<0.02

TABLE 7.3-9 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
PHASE IB

Parameter and Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,2,3-Trichlorobenzene by CLS					
Number Det'd/Number	1/6	NM	1/7	0/8	0/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.001/<0.03		<0.001/<0.03	<0.001/<0.001	<0.001/<0.001
1,2,4-Trichlorobenzene by CLS					
Number Det'd/Number	4/6	NM	2/7	0/8	0/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.02/<0.02		<0.001/<0.02	<0.001/<0.001	<0.001/<0.001
Acetone by VOA					
Number Det'd/Number	1/6	NM	2/8	2/8	2/8
Geometric Mean/Spread Factor	NC		0.15/7.12	0.28/2.42	0.17/4.72
Median/90% Value	<0.5/2.3		<0.5/2.6	<0.5/1.2	<0.5/2.8
Geosmin by CLS					
Number Det'd/Number	1/6	NM	1/7	0/8	0/6
Geometric Mean/Spread Factor	NC		NC	NC	NC
Median/90% Value	<0.0005/<0.05		<0.0005/<0.05	<0.0005/<0.0005	<0.0005/<0.0005

a. NM = Not Measured.

b. NC = Not Calculated (i.e., less than fifteen percent of samples were  $\geq$  MDL).

## SECONDARY ORGANIC COMPOUNDS

Figures 7.3-34 and 7.3-35 show the fate of secondary organic compounds (i.e., those tentatively identified) at the EEWTP detected at least once during Phases IA and IB, respectively. The figures show that fewer compounds were found at all four sites during Phase IB than during Phase IA. This is primarily because fewer samples were taken during the shorter Phase IB.

Tables 7.3-10 and 7.3-11 list those secondary organic compounds detected in more than fifteen percent of the samples from at least one of the four sites. Only 9 out of the 52 compounds listed for Phase IA and 4 out of the 44 compounds listed for Phase IB were detected at concentrations greater than or equal to 1  $\mu\text{g/L}$ . In Phase IA, a smaller number of the detected secondary compounds were found as frequently in the blended influent. At each of the other three sites, however, fewer of these compounds were found more than fifteen percent of the time during Phase IB. Comparisons between Phases IA and IB for secondary organic compounds can only be qualitative. Quantitative comparisons can only be made for a number of primary organic compounds.

## SUMMARY

Of the large number of organic compounds which have been detected in natural waters, a relatively small fraction was identified in the EEWTP blended influent during Phases IA and IB. This was due to two main factors related to analytical capabilities. First, available analytical techniques were capable of detecting mostly low molecular weight, polar compounds. Second, detection limits of the techniques limited the number of compounds that could be detected. However, the MDLs for many primary compounds are on the order of 1  $\mu\text{g/L}$ . For those primary and secondary compounds detected in the EEWTP blended influent during Phases IA and IB, the combination of unit processes up through GAC appeared to provide an adequate barrier against the passage of trace organics into the EEWTP finished water.

TABLE 7.3-10

SECONDARY ORGANIC COMPOUNDS DETECTED IN  
MORE THAN FIFTEEN PERCENT OF SAMPLES  
FREQUENCY OF OCCURRENCE/RANGE OF VALUES  
PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
<b>2-Methylbutane</b>				
No. Det'd/Number	4/19	1/8	1/20	0/18
Range <sup>a</sup>	NQ <sup>b</sup> -0.5	0.2	NQ	ND <sup>c</sup>
<b>1-Butene</b>				
No. Det'd/Number	4/19	1/8	3/20	3/18
Range	NQ-0.3	0.6	NQ	NQ
<b>1,1'-Oxybisethane</b>				
No. Det'd/Number	13/19	5/8	12/20	11/18
Range	NQ-1.7	0.1-1.1	NQ-1.1	NQ-0.7
<b>2,2'-Oxybispropane</b>				
No. Det'd/Number	10/19	4/8	7/20	5/18
Range	NQ-1.8	0.2-1.6	NQ-2.1	NQ-1.1
<b>Thiobismethane</b>				
No. Det'd/Number	4/19	0/8	0/20	0/18
Range	NQ-1.5	ND	ND	ND
<b>2-Methylbutanal</b>				
No. Det'd/Number	0/19	0/8	0/20	3/18
Range	ND	ND	ND	NQ
<b>Nonanal</b>				
No. Det'd/Number	0/19	0/8	0/20	3/18
Range	ND	ND	ND	NQ
<b>Pentanal</b>				
No. Det'd/Number	0/19	0/8	0/20	5/18
Range	ND	ND	ND	NQ
<b>Dodecanoic Acid</b>				
No. Det'd/Number	4/5	4/5	2/5	2/5
Range	2-7	1-4	1-7	2-6
<b>Hexodecanoic Acid</b>				
No. Det'd/Number	4/5	4/5	3/5	3/5
Range	2-36	1-5	1-2	3-5



# Fate of Contaminants

TABLE 7.3-10 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
13,16-Octadecanoic No. Det'd/Number Range	1/5 2.0	0/5 ND	0/5 ND	0/5 ND
Octadecanoic Acid No. Det'd/Number Range	2/5 3-18	2/5 1-4	1/5 2	2/5 4
Tetradecanoic Acid No. Det'd/Number Range	4/5 1-9	3/5 1-2	1/5 1	2/5 2
1,1,1-Trichloroethane No. Det'd/Number Range	5/9 .13-5.5	5/8 .13-2.5	5/9 .034-2.0	5/9 .053-2.2
1,2,3-Trichloropropane No. Det'd/Number Range	0/9 ND	2/8 .0078-.010	2/9 .0082-.029	0/9 ND
(1,1-Dimethylethyl)benzene No. Det'd/Number Range	0/9 ND	2/8 .021-.044	0/9 ND	0/9 ND
(1,1-Dimethylpropyl)benzene No. Det'd/Number Range	0/9 ND	2/8 .032-.061	0/9 ND	0/9 ND
1-Ethyl-2,4-dimethylbenzene No. Det'd/Number Range	0/9 ND	2/8 .037-.038	0/9 ND	0/9 ND
1-Ethyl-3,5-dimethylbenzene No. Det'd/Number Range	1/9 .014	2/8 .037-.038	0/9 ND	0/9 ND
2-Ethyl-1,4-dimethylbenzene No. Det'd/Number Range	1/9 .053	4/8 .015-.059	0/9 ND	1/9 .0044

# Fate of Contaminants

TABLE 7.3-10 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
4-Ethyl-1,2-dimethylbenzene				
No. Det'd/Number	3/9	4/8	1/9	2/9
Range	.016-.026	.017-.042	.0052	.0064-.010
1-Ethyl-2-methylbenzene				
No. Det'd/Number	7/9	8/8	4/9	7/9
Range	.0034-.077	.017-.26	.0042-.017	.0043-.032
1-Ethyl-4-methylbenzene				
No. Det'd/Number	7/9	8/8	1/9	3/9
Range	.0037-.048	.0062-.17	.0046	.0076-.011
(1-Methylethyl)benzene				
No. Det'd/Number	1/9	3/8	2/9	2/9
Range	.0076	.0034-.066	.0022-.0042	.0026-.007
1,2,3,5-Tetramethylbenzene				
No. Det'd/Number	1/9	6/8	0/9	0/9
Range	.031	.0032-.11	ND	ND
1,2,4,5-Tetramethylbenzene				
No. Det'd/Number	4/9	6/8	0/9	1/9
Range	.016-.034	.0034-.11	ND	.0077
1,2,3-Trimethylbenzene				
No. Det'd/Number	7/9	8/8	6/9	6/9
Range	.021-.12	.021-.28	.0020-.032	.0046-.068
1,2,4-Trimethylbenzene				
No. Det'd/Number	5/9	8/8	4/9	4/9
Range	.020-.037	.0054-.13	.0042-.0088	.0046-.017
1,2,5-Trimethylbenzene				
No. Det'd/Number	0/9	2/8	1/9	1/9
Range	ND	.031-.075	.0083	.016
1,3,5-Trimethylbenzene				
No. Det'd/Number	6/9	6/8	3/9	3/9
Range	.0053-.092	.0099-.36	.0047-.0093	.0062-.013

# Fate of Contaminants

TABLE 7.3-10 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
<b>2-Methylnaphthalene</b>				
No. Det'd/Number	0/9	3/8	0/9	0/9
Range	ND	.0038-.018	ND	ND
<b>1,2,3,4-Tetrahydro-2,6-dimethylnaphthlene</b>				
No. Det'd/Number	0/9	2/8	0/9	0/9
Range	ND	.041-.076	ND	ND
<b>1,2,3,4-Tetrahydronaphthalene</b>				
No. Det'd/Number	1/9	2/8	0/9	0/9
Range	.038	.014-.14	ND	ND
<b>1,3-Dimethylinden</b>				
No. Det'd/Number	0/9	2/8	0/9	0/9
Range	ND	.0073-.0095	ND	ND
<b>Indan</b>				
No. Det'd/Number	1/9	2/8	2/9	2/9
Range	.031	.046-.049	.011-.020	.017-.029
<b>4,4-Dimethyl-2-pentanone</b>				
No. Det'd/Number	0/9	2/8	0/9	0/9
Range	ND	.011-.024	ND	ND
<b>4-Methyl-2-pentanone</b>				
No. Det'd/Number	2/9	2/8	2/9	2/9
Range	.051-.060	.031-.043	.028-.067	.032-.45
<b>1-Methyl-4-(1-methylethyl)-7-Oxabiscyclo-(2.2.1)-heptane</b>				
No. Det'd/Number	3/9	5/8	3/9	3/9
Range	.017-.062	.0079-.096	.0044-.032	.015-.025
<b>1,3,3-Trimethylbicyclo-(2.2.1)heptan-2-ol</b>				
No. Det'd/Number	2/9	2/8	2/9	2/9
Range	.011-.070	.015-.052	.0056-.012	.0077-.014
<b>Decanal</b>				
No. Det'd/Number	1/9	3/8	2/9	3/9
Range	.080	NQ-.033	.0092-.0093	.015-.069

# Fate of Contaminants

TABLE 7.3-10 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
Heptanal No. Det'd/Number Range	2/9 .013-.044	0/8 ND	0/9 ND	0/9 ND
Hexanal No. Det'd/Number Range	4/9 .0065-.100	5/8 .019-.061	0/9 ND	1/9 .044
Eicosane No. Det'd/Number Range	5/9 .042-.900	0/8 ND	2/9 .013-.014	0/9 ND
5-Ethyl-2-methylheptane No. Det'd/Number Range	2/9 .038-.051	0/8 ND	0/9 ND	0/9 ND
Octadecane No. Det'd/Number Range	7/9 .0061-.145	0/8 ND	0/9 ND	0/9 ND
2,6,10,14-Tetramethylheptadecane No. Det'd/Number Range	6/9 .015-.100	0/8 ND	1/9 .011	0/9 ND
2,2,3-Trimethylhexane No. Det'd/Number Range	3/9 .013-.17	1/8 .014	0/9 ND	0/9 ND
2,2,4-Trimethyl-1-pentane No. Det'd/Number Range	2/9 .046-.22	0/8 ND	0/9 ND	0/9 ND
5-methyl-2-(1-methylethyl)cyclohexane No. Det'd/Number Range	0/9 ND	2/8 .028-.057	0/9 ND	0/9 ND
1-(1-Cyclohexenyl-1-yl)-1-propanone No. Det'd/Number Range	0/9 ND	1/8 .051	2/9 .012-.022	1/9 .0074

# Fate of Contaminants

TABLE 7.3-10 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IA

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
1-Methyl-4-(1-methylethyl)cyclohexene				
No. Det'd/Number	3/9	1/8	2/9	2/9
Range	.015-.038	.046	.0046-.0062	.0029-.071
2-Methylpropanoic acid butyl ester				
No. Det'd/Number	2/9	2/8	0/9	0/9
Range	.065-.261	.037-.110	ND	ND

- a. All concentrations in  $\mu\text{g/L}$ .  
b. NQ = Not Quantified.  
c. ND = Not Detected.

# Fate of Contaminants

TABLE 7.3- 1

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IB

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
1,3-Diethylbenzene				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	0.0086	ND <sup>1</sup>	ND	ND
1-Ethyl-2-Methylbenzene				
No. Det'd/Number	2/6	5/7	3/8	3/6
Range	.029-.036	.012-.032	.0077-.012	.015-.022
1-Ethyl-4-Methylbenzene				
No. Det'd/Number	1/6	1/7	0/8	1/6
Range	.009	.0059	ND	ND
1,2,3-Trimethylbenzene				
No. Det'd/Number	4/6	6/7	4/8	3/6
Range	.0062-.036	.011-.025	.0084-.015	.0057-.018
1,2,4-Trimethylbenzene				
No. Det'd/Number	2/6	2/7	1/8	0/6
Range	.014-.084	.0038-.0073	.0018	ND
2,2-Dimethyl-3-hexanone				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.016	ND	ND	ND
4-Hydroxy-4-methyl-2-pentanone				
No. Det'd/Number	1/6	1/7	0/8	0/6
Range	.022	.030	ND	ND
Isophorone				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.160	ND	ND	ND
6-Methyl-1-octanol				
No. Det'd/Number	1/6	1/7	0/8	0/6
Range	.0067	.0058	ND	ND
Decanal				
No. Det'd/Number	3/6	4/7	3/8	1/6
Range	.0079-.018	.010-.024	.0053-.027	.0078

# Fate of Contaminants

TABLE 7.3-11 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IB

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
3,3-Dimethylhexanal No. Det'd/Number Range	1/6 .0028	0/7 ND	0/8 ND	0/6 ND
2-Ethylhexanal No. Det'd/Number Range	0/6 ND	0/7 ND	0/8 ND	1/6 .019
Nonanal No. Det'd/Number Range	2/6 .012-.031	3/7 .011-.018	3/8 .011-.022	0/6 ND
Hexanal No. Det'd/Number Range	1/6 .018	0/7 ND	1/8 .0075	0/6 ND
4-Methylhexanal No. Det'd/Number Range	1/6 .004	0/7 ND	0/8 ND	0/6 ND
Tetradecanal No. Det'd/Number Range	0/6 ND	2/7 .0015-0.20	0/8 ND	0/6 ND
2,5-Dimethylheptane No. Det'd/Number Range	1/6 .010	0/7 ND	0/8 ND	0/6 ND
Eicosane No. Det'd/Number Range	1/6 .0077	0/7 ND	0/8 ND	0/6 ND
5-Ethyl-2-Methylheptane No. Det'd/Number Range	1/6 .009	0/7 ND	0/8 ND	0/6 ND
Hexadecane No. Det'd/Number Range	1/6 .0045	0/7 ND	0/8 ND	0/6 ND

# Fate of Contaminants

TABLE 7.3-11 (Continued)

## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IB

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
Octadecane				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.026	ND	ND	ND
2,2,4,6,6-Pentamethylheptane				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.026	ND	ND	ND
2,6,10,14-Tetramethylheptadecane				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.022	ND	ND	ND
2,2,4-Trimethylhexane				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.014	ND	ND	ND
7-Methyl-6-Tridecene				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.011	ND	ND	ND
4,6,8-Trimethyl-1-nonene				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.004	ND	ND	ND
1-Ethenyl-2-hexenylcyclopropane				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.025	ND	ND	ND
Butyl acetate				
No. Det'd/Number	0/6	0/7	0/8	1/6
Range	ND	ND	ND	.023
2-Methyl propanoic acid butyl ester				
No. Det'd/Number	1/6	3/7	2/8	0/6
Range	.046	.015-.045	.017-.021	ND
Dimethyldisulfide				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.011	ND	ND	ND



# Fate of Contaminants

TABLE 7.3-11 (Continued)

SECONDARY ORGANIC COMPOUNDS DETECTED IN  
MORE THAN FIFTEEN PERCENT OF SAMPLES  
FREQUENCY OF OCCURRENCE/RANGE OF VALUES  
PHASE IB

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
Dimethyltrisulfide				
No. Det'd/Number	1/6	0/7	0/8	0/6
Range	.0058	ND	ND	ND
Hexadecanoic acid				
No. Det'd/Number	1/3	1/4	1/4	0/4
Range	0.3	0.4	0.1	ND
Octadecanoic acid				
No. Det'd/Number	1/3	1/4	0/4	0/4
Range	0.2	0.2	ND	ND
Tetradecanoic acid				
No. Det'd/Number	1/4	1/4	1/4	1/4
Range	0.4	0.2	0.1	0.2
2,6-Bis(1,1-Dimethylethyl)-4-methyl phenol				
No. Det'd/Number	1/4	1/4	1/4	1/4
Range	2.3	2.2	1.9	1.9
1,2-Dichloro-1,1,2,2-Tetrafluorethane				
No. Det'd/Number	1/6	1/9	1/8	1/8
Range	0.9	4.1	1.7	4.1
2,4-Dimethylpentane				
No. Det'd/Number	1/6	0/9	0/8	1/8
Range	0.1	ND	ND	0.1
2-Methylbutane				
No. Det'd/Number	1/6	0/9	0/8	0/8
Range	0.4	ND	ND	ND
2-Methylpropane				
No. Det'd/Number	1/6	7/9	0/8	0/8
Range	1.0	0.8	ND	ND
Dimethoxypropane				
No. Det'd/Number	1/6	0/9	0/8	0/8
Range	0.4	ND	ND	ND

# Fate of Contaminants

TABLE 7.3-11 (Continued)

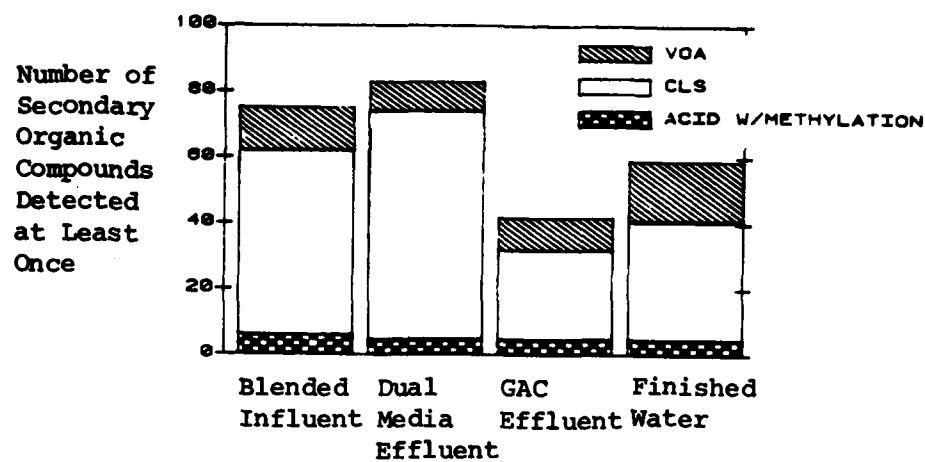
## SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES FREQUENCY OF OCCURRENCE/RANGE OF VALUES PHASE IB

<u>Compound</u>	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>	<u>Finished Water</u>
1,1-Dimethoxypropane				
No. Det'd/Number	2/6	2/9	2/8	2/8
Range	0.4-0.7	0.3-0.4	0.3	0.2-0.3
1,1-Oxybisethane				
No. Det'd/Number	3/6	1/9	0/8	1/8
Range	0.4-1.1	0.5	ND	NQ <sup>c</sup>
1,1-Oxybismethane				
No. Det'd/Number	1/6	0/9	1/8	0/8
Range	0.6	ND	0.8	ND
2,2-Oxybispropane				
No. Det'd/Number	3/6	0/9	0/8	0/8
Range	0.1-0.3	ND	ND	ND

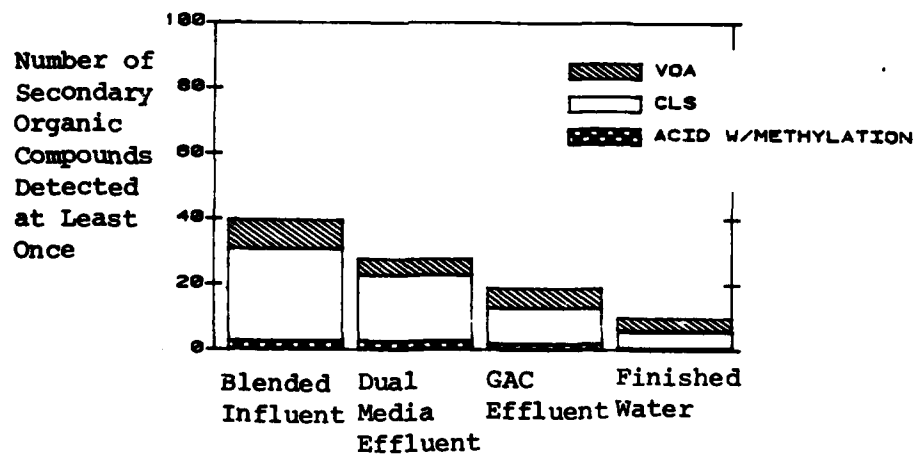
a. All concentrations in µg/L.

b. ND = Not Detected

c. NQ = Not Quantified.



**FATE OF SECONDARY ORGANIC COMPOUNDS (PHASE IA)**  
**FIGURE 7. 3- 34**



**FATE OF SECONDARY ORGANIC COMPOUNDS (PHASE IB)**  
**FIGURE 7. 3- 35**

## TOXICOLOGICAL

### AMES TEST

Mutagenicity in units of specific activity (revertants/L) is compared below at four EEWTP sampling locations: blended influent, dual media filter effluent, final carbon column effluent (GAC) and the finished water. Mean specific activity is calculated as the arithmetic average of results from individual samples. Further details concerning the calculation of specific activity in the Ames assay are provided in Section 8 of Chapter 9.

#### Phase IA

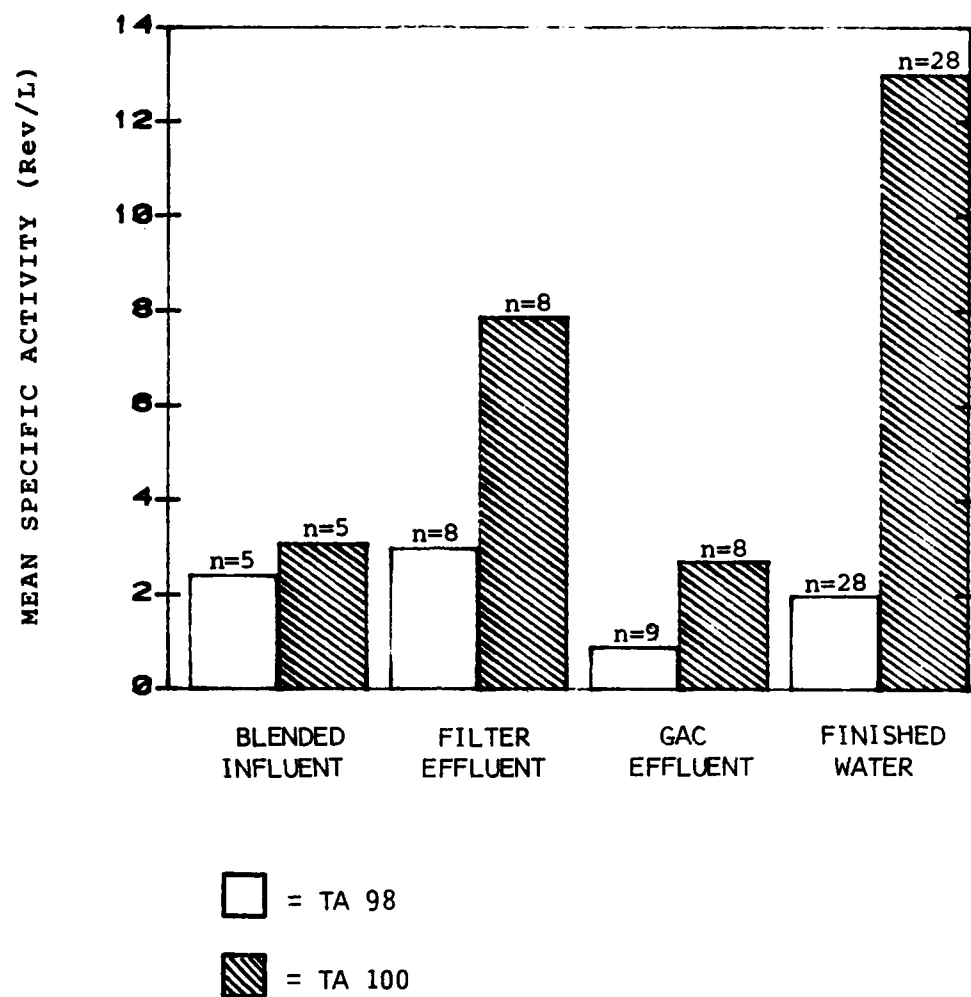
As shown in Figure 7.3-36, the GAC removed approximately sixty to seventy percent of the specific activity entering the columns from the gravity filter effluent. Chlorination of the GAC effluent increased the mutagenicity using TA98 and TA100 Salmonella tester strains, both without metabolic activation. Specific activity was greater in the filter effluent than the blended influent, possibly as a result of intermediate disinfection with chlorine ahead of the filter.

#### Phase IB

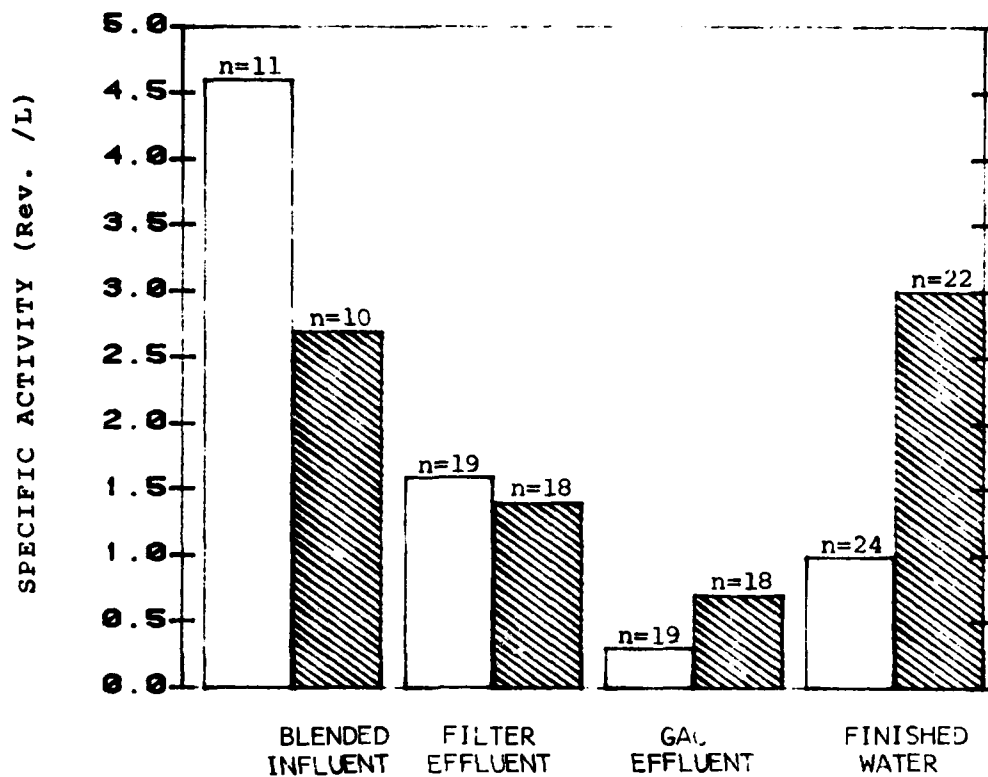
The GAC columns were also effective in Phase IB in removing mutagenic compounds from the filter effluent (Figure 7.3-37). Specific activity decreased by 81 percent using TA98 and fifty percent for TA100, both without metabolic activation. Final chlorine disinfection increased the mean specific activity in the finished water for both strains. Specific activity in the filter effluent was lower in Phase IB compared to Phase IA, due possibly to replacement of chlorine with ozone as the intermediate oxidant. The chlorination showed more mutagens than ozonation.

### MAMMALIAN CELL TRANSFORMATION ASSAY

Because this assay was only conducted on the finished water, results are presented in Section 8 of Chapter 9.



**SPECIFIC ACTIVITY IN EEWTP PROCESSES  
(PHASE IA)  
FIGURE 7. 3-36**



□ = TA 98

▨ = TA 100

**SPECIFIC ACTIVITY IN EEWTP PROCESSES  
(PHASE IB)**

**FIGURE 7. 3-37**

## SECTION 4

### PROCESS ANALYSIS

During the operation of the EEWTP for Phases IA and IB, the individual processes were evaluated to determine performance with respect to key water quality parameters, and to determine the effect of operational conditions (loading rates, chemical doses, backwashing) and environmental factors (pH, temperature) on performance and reliability. This section presents the results of these evaluations for the processes of chemical clarification (chemical addition, rapid mixing, flocculation and sedimentation), gravity filtration, granular activated carbon and disinfection with free chlorine. Where appropriate, the results have been used as the basis for specification of design criteria used for cost estimates of the estuary water treatment plant, as presented in Chapter 11.

#### CHEMICAL CLARIFICATION

The process objectives and operational characteristics of the chemical clarification process were presented in Section 1 of this chapter. The key operational and design criteria for this process are:

- o Dose of primary coagulant (alum in this case)
- o Type and dose of coagulant aid
- o pH
- o Mixing conditions (intensity, detention time) in rapid mix
- o Mixing conditions in flocculation
- o Detention time, superficial loading rate, and weir loading rate in the sedimentation basin.

Of these main operational design criteria, only the chemical conditions in the coagulation step were investigated with respect to impact on overall process performance. All other factors were held constant during the Phase IA and IB operations.

The chemical clarification process should be designed and operated to maximize removals of selected contaminants with a minimum expenditure of chemicals and energy. The process consists of three steps: (1) formation of insoluble precipitates (rapid mixing), (2) agglomeration (flocculation) of the precipitates into floc particles of sufficient size and density for settling, and (3) sedimentation.

Tracer studies of the rapid mix and flocculation basins (see Appendix I, Section 10) revealed that the mixing basins were completely mixed reactors and that mixing conditions were sufficient to provide adequate opportunities for floc

## Process Analysis

agglomeration. Tracer studies of the sedimentation basin showed considerable short circuiting, but the mean detention time determined by the tracer test suggested that the sedimentation step was not limiting the overall process performance with respect to removal of the flocculent solids produced in the coagulation/flocculation steps.

The principal factors that appeared to control the performance of the chemical clarification process were:

- o alum dose
- o pH
- o temperature
- o polymer dose

It was not possible to evaluate the effect of the ionic environment (TDS, concentration of specific inorganic ions) on the process performance. The impact of these removal factors on several key water quality parameters are discussed.

### TURBIDITY

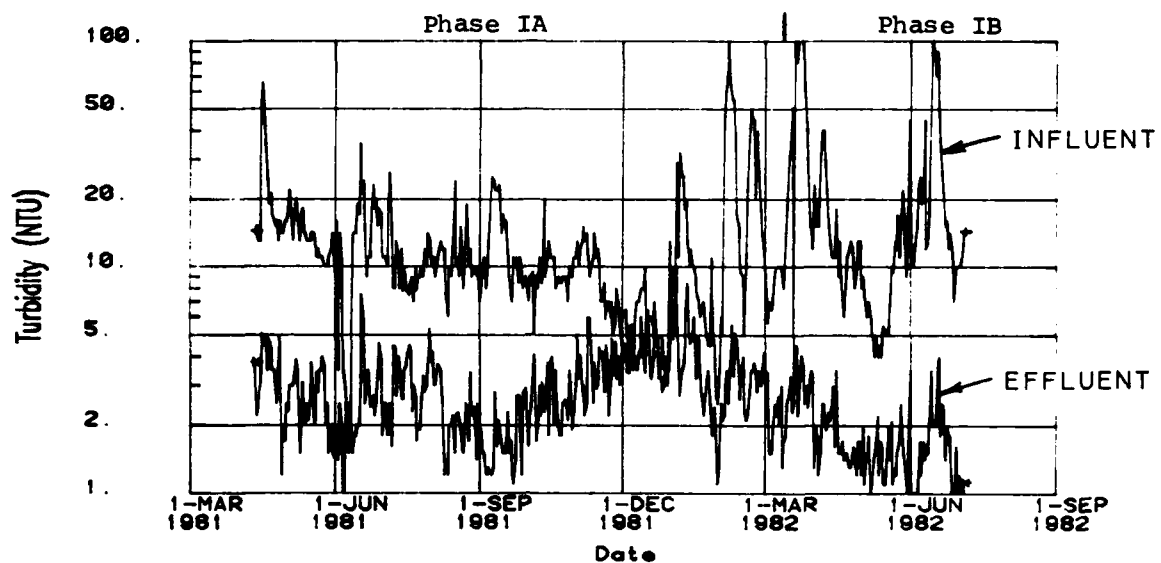
The performance of the chemical clarification process with respect to turbidity removal is shown in Figure 7.4-1. The time-series plot of turbidity in the blend tank (influent) and the sedimentation tank effluent indicate fluctuating removals, with the effluent turbidity typically less than 5 NTU during Phase IA, and less than 3 NTU during Phase IB. Noticeable decreases in turbidity removal occurred between 1 December 1981 and 1 March 1982, probably as a result of colder water temperatures. In contrast, improved removals were noted during Phase IB, as shown.

### TOC

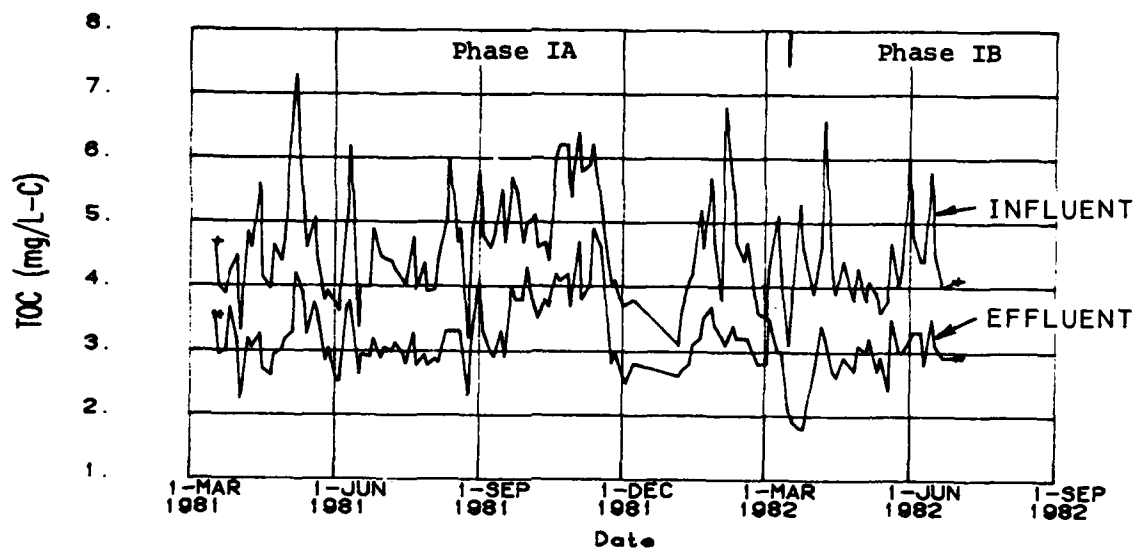
The influent and effluent levels of total organic carbon (TOC) across the chemical clarification process are shown in Figure 7.4-2 for both Phase IA and Phase IB. TOC consists of both particulate and dissolved (smaller than 0.45  $\mu\text{m}$ ) organic material, some portion of which can be removed by chemical coagulation. As shown, under the conditions tested, TOC removals varied between approximately ten and fifty percent. Overall, the average removals, based on geometric mean values, were 32 percent and 42 percent for Phases IA and IB, respectively.

Removal of total organic halide (TOX) was also monitored in the chemical clarification process. Observed removals for Phases IA and IB were 22 percent and 37 percent, respectively. Values in the sedimentation effluent ranged between 40 to 70  $\mu\text{g/L-Cl}$ . Statistical summaries of the TOC and TOX data are shown in Appendix G.





**CHEMICAL CLARIFICATION  
INFLUENT AND EFFLUENT TURBIDITY  
(PHASES IA & IB)  
FIGURE 7. 4-1**



**CHEMICAL CLARIFICATION  
INFLUENT AND EFFLUENT TOC  
(PHASES IA & IB)  
FIGURE 7. 4-2**

### PROCESS VARIABLES

Figures 7.4-3 and 7.4-4 display the average daily alum dose and the pH values in the sedimentation tank effluent for Phases IA and IB. As shown, both the alum dose and process pH were varied during the operational periods to evaluate the impact of these factors on performance.

Between 1 June and 1 September 1981, process pH varied between pH 6 and pH 7. During this period the water temperature increased from 20°C to about 28°C (see Figure 7.2-1). As shown in Figures 7.4-1 and 7.4-2, turbidity and TOC removals were relatively constant, with effluent values of turbidity less than 4 NTU and TOC values less than 3 mg/L-C. Alum dose ranged from 45 mg/L to 70 mg/L, with no apparent increase in turbidity or TOC removal with the increasing alum dose.

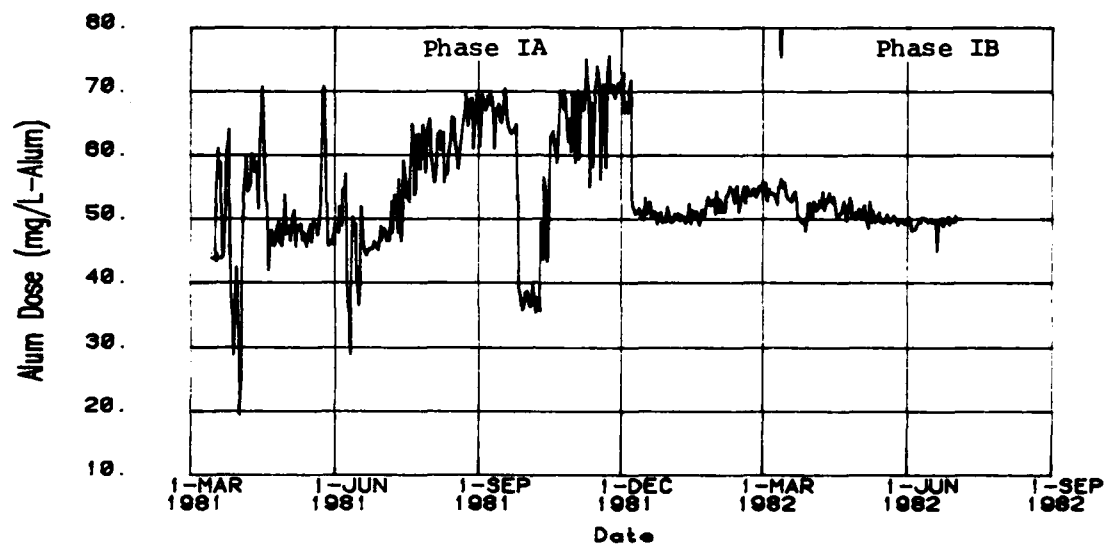
During October, 1981, a lower dose of alum (approximately 35 mg/L) in combination with 0.20 mg/L of a cationic polymer, Betz 1160, was tested to verify bench test results, which had indicated that satisfactory TOC and turbidity removals could be achieved but with lower production of alum sludge. The lower alum dose is shown in Figure 7.4-3.

As seen in Figure 7.4-2, the test results were negative, as the TOC values in the sedimentation effluent increased above 4 mg/L-C. Turbidity removals also deteriorated slightly (Figure 7.4-1). Several factors may have caused the failure of this coagulant combination, including higher pH (see Figure 7.4-4 showing pH increase due to the addition of lime, and lower alum doses), decreasing temperature (see Figure 7.4-1), and an increase in TOC levels in the blended effluent. The character of the dissolved organic material may have also changed, with a higher fraction of organic matter not susceptible to removal by coagulation.

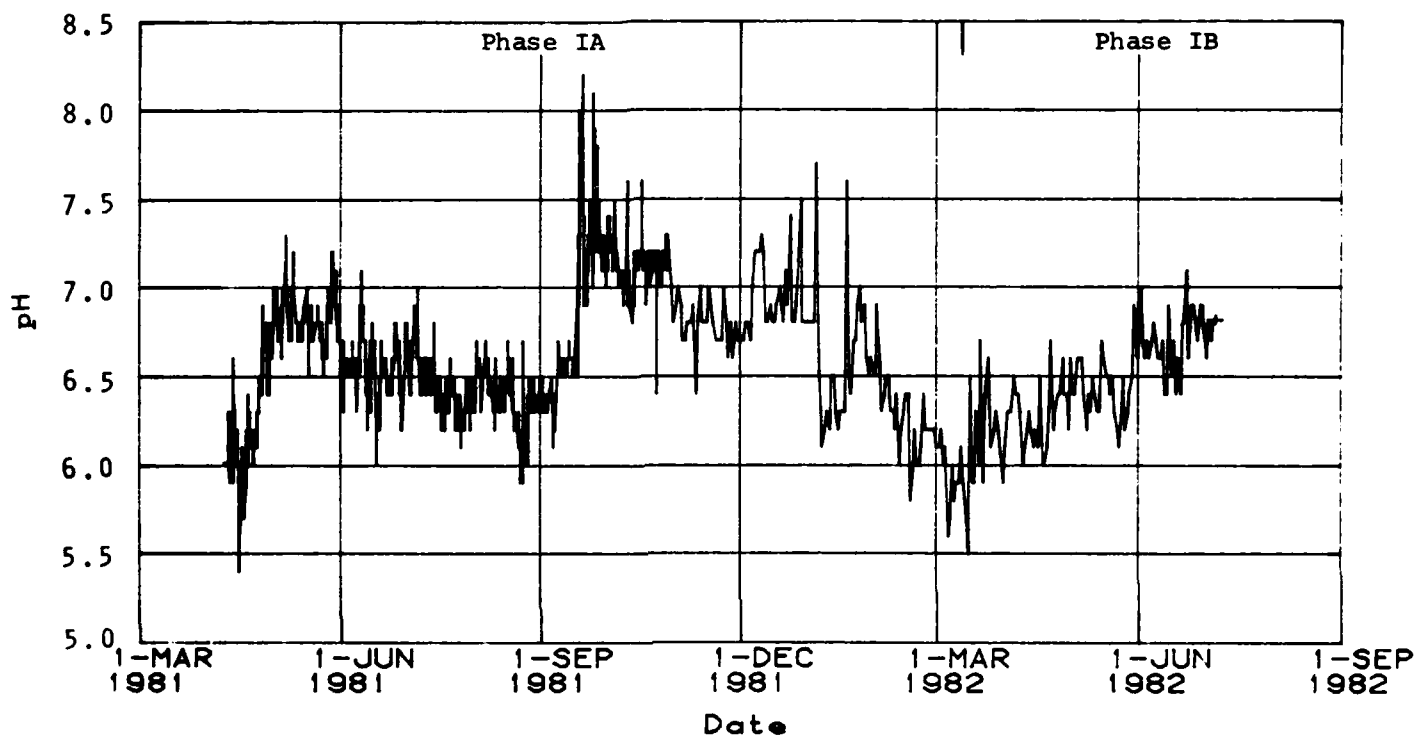
During the winter months of 1981 and 1982, the turbidity removals by chemical clarification decreased substantially, as shown in Figure 7.4-1. The poor removals are attributed primarily to lower water temperature, as shown in Figure 7.2-1, with the water reading its minimum temperature of 8°C in early February.

From December 1981 through the end of Phase IB (7 July 1982), the alum dose was held essentially constant at about 50 mg/L-alum. Turbidity and TOC removals during Phase IB were relatively constant, and slightly greater than during Phase IA, as shown in Figure 7.4-1 and 7.4-2.

At a 50 mg/L average alum dose, the average solids production was 300 lbs/MG. The individual weekly sampling results suggest that more solids were produced at higher alum doses, as expected.



AVERAGE DAILY ALUM DOSE  
(PHASES IA & IB)  
FIGURE 7. 4-3



**CHEMICAL CLARIFICATION EFFLUENT pH  
(PHASES IA & IB)  
FIGURE 7. 4-4**

## GRAVITY FILTRATION

Chemical clarification was followed by intermediate disinfection and gravity filtration with dual media filters, as previously discussed. Disinfection of the filter influent was accomplished by chlorine addition during Phase IA and by ozonation (10 minute contact) during Phase IB. The key design parameters for gravity filtration are surface loading rate, media design, and pretreatment. Two different pretreatment modes were tested in the EEWTP, as mentioned, corresponding to Phases IA and IB of operation. Two different surface loading rates were also tested. As in coagulation, the performance of gravity filtration is based in part on removal of particulate contaminants. The surface loading rate to the gravity filters was maintained at 3 gpm/ft<sup>2</sup> throughout Phase I except for the periods of 8 March 1982 through 13 March 1982 and 8 June 1982 through 4 July 1982. During these two periods the surface loading rate was 6 gpm/ft<sup>2</sup>.

As discussed in Section 1 of this chapter, backwashing of the filters was initiated when one of the following occurred:

- Filter effluent turbidity approached or exceeded 0.5 NTU.
- Headloss through the filter approached or exceeded 60 percent of the available head, approximately 6 feet of water.
- Three days had passed since the last backwash.

The most frequently exceeded criterion was turbidity, followed by headloss. Backwashing based on the 3-day requirement occurred infrequently, most notably when estuary water alone was processed.

The two filtered water quality parameters used to evaluate filter performance were turbidity and TOC.

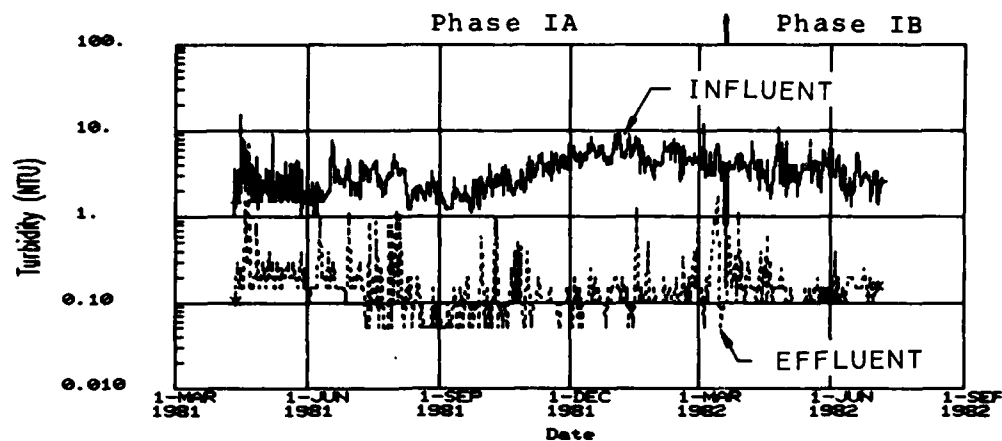
### TURBIDITY

Throughout most of Phase I there was a ten-fold reduction of turbidity across the filters. During Phase IA the geometric mean of the influent water turbidity was 3.04 NTU, and the filtered water was 0.13 NTU. The corresponding values for Phase IB were 3.09 and 0.14 NTU. Both filtered water turbidity values were well below the EPA Primary Drinking Water Standard of 1 NTU. Figure 7.4-5 shows the turbidity of the filter influent and effluent during Phase I.

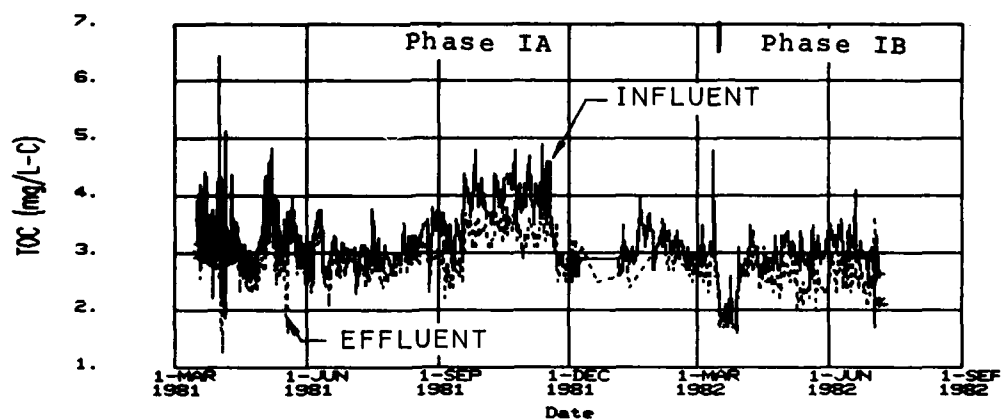
### TOC

The removal of total organic carbon (TOC) by gravity filtration is of interest because TOC removal via filtration may reduce costs for TOC adsorption in the granular activated carbon process. Filtration influent and effluent TOC values are shown in Figure 7.4-6.

Table 7.4-1 contains the geometric means of the sedimentation effluent TOC and filtered water effluent TOC and the percent reduction for the Phase I



**FILTRATION: INFLUENT AND EFFLUENT TURBIDITY  
(PHASES IA AND IB)  
FIGURE 7. 4-5**



**FILTRATION: INFLUENT AND EFFLUENT TOC  
(PHASES IA AND IB)  
FIGURE 7. 4-6**

## Process Analysis

filtration process. In both Phases IA and IB, the percent reduction of TOC by the filters was approximately ten percent.

TABLE 7.4-1  
TOC REDUCTION IN THE FILTRATION PROCESS

	TOC, mg/L (Geometric Mean)		
	<u>Filter Influent</u>	<u>Filter Effluent</u>	<u>Removal (percent)</u>
Phase IA	3.26	2.92	10
Phase IB	2.83	2.47	13

## WATER PRODUCTION

A convenient method of quantifying the net water production is by the unit filter run volume (UFRV). The UFRV is equal to the unit volume of water produced (volume produced per square foot of filter area) minus the unit volume of backwash water used. Three factors affect net water production: the filtration rate, the length of filter run, and the amount of water required for backwash. Studies have shown that when the UFRV drops below 5,000 gal/ft<sup>2</sup>/run, the efficiency of water production decreases rapidly. Above 5,000 gal/ft<sup>2</sup>/run efficiency increases but only gradually. Thus, gravity filters should be designed and operated such that the UFRV is greater than 5,000 gal/ft<sup>2</sup>/run.

Table 7.4-2 summarizes water production data at 3 gpm/ft<sup>2</sup>. At this rate in Phase I, the UFRV never fell below 7,000 gal/ft<sup>2</sup>/run. The average UFRV was 9,989 gal/ft<sup>2</sup>/run. There appeared to be no problem maintaining adequate UFRVs and production efficiencies during 3 gpm/ft<sup>2</sup> operation in Phase I. (The filter production efficiency is the water produced minus the volume of backwash water divided by the water produced.)

Table 7.4-3 presents the filter performance data for the two periods in Phase I during which the filters were operated at 6 gpm/ft<sup>2</sup>. During the first period no intermediate ozonation was used. Filter run times during this period averaged 21.6 hours and the UFRV averaged 7,490 gal/ft<sup>2</sup>/run. Effluent turbidities during this time period were somewhat higher than at the lower loading rate. As shown in Table 7.4-3, turbidity at backwashing was quite high and often represented the backwash criterion. During the second period, when intermediate ozonation was in effect, the average filter run time was 46.5 hours and the average UFRV was 16,532 gal/ft<sup>2</sup>/run. The increases in filter run time (115 percent) and in UFRV (121 percent) when ozonation was used were substantial. Effluent turbidity also increased at a much slower rate during the test run than in the previous 6 gpm/ft<sup>2</sup> run, and turbidity was never the cause for backwashing.



# Process Analysis

TABLE 7.4-2  
GRAVITY FILTER WATER PRODUCTION DATA AT 3 gpm/ft<sup>2</sup> - PHASE I

Month	Average Time Between Backwash (hrs)	Backwash Volume, (gal)	Average Unit Filter Run Volume (gal/ft <sup>2</sup> /run)	Net Water Production (Percent)
March, 1981	68	11,409	12,145	99.2
April	48	12,537	8,536	98.8
May	62	12,344	11,057	99.1
June	81	13,370	14,469	99.1
July	65	12,952	11,592	99.1
August	71	10,695	12,691	99.3
September	55	10,808	9,810	99.1
October	50	10,660	8,911	99.0
November	47	11,099	8,368	98.9
December	53	11,000	9,448	99.0
January, 1982	43	10,238	7,655	98.9
February	40	19,544	7,037	97.7
March <sup>1</sup>	50	10,351	8,914	99.0
April	43	10,816	7,650	98.8
May	65	18,515	11,546	98.7
Average	56	12,423	9,989	98.9

1. March 8 - 14 not included since filters were run at 6 gpm/ft<sup>2</sup> during that time.

# Process Analysis

TABLE 7.4.3  
SUMMARY OF FILTER OPERATION AT 6 gpm/ft<sup>2</sup> - PHASE I

Experiment Number	Filter Number Used	Run Time, (hrs)	Headloss at Backwash (in ft H <sub>2</sub> O)	Effluent Turbidity at Backwash, (NTU)	Influent Turbidity at Backwash (NTU)	Unit Production (gal/ft <sup>2</sup> /run)	Unit Backwash (gal/ft <sup>2</sup> /run)	UFRV (gal/ft <sup>2</sup> /run)
CONDITION: Alum With No Ozone DATES: 8 March - 14 March 82								
1	1	18.0	48.6	1.3	5.1	6,480	214	6,266
2	2	19.8	62.6	0.7	4.0	7,110	325	6,785
3	1	16.9	36.7	0.4	3.9	6,084	245	5,839
4	2	23.3	54.0	1.1	3.6	8,388	245	8,143
5	1	24.5	57.2	0.9	3.6	8,820	341	8,479
6	2	24.5	54.0	1.0	5.4	8,820	314	8,506
7	1	24.0	21.6	1.7	3.9	8,640	227	8,413
AVERAGE		21.6	—	—	—	—	273	7,490
CONDITION: Alum With Ozone DATES: 8 June 82 - 4 July 82								
1	1	52.0	81.0	0.2	2.1	18,720	181	18,539
2	2	43.5	70.2	0.25	2.4	15,660	181	15,479
3	1	37.0	43.2	0.60	2.1	13,320	182	13,138
4	2	29.0	<21.6	0.40	2.8	10,440	266	10,174
5	1	56.5	64.8	0.15	2.4	20,340	239	20,101
6	2	19.8	<21.6	1.2	3.2	7,110	239	6,871
7	1	43.0	30.2	0.75	4.7	15,480	199	15,281
8	2	64.0	64.8	0.25	2.9	23,040	197	22,843
9	1	55.5	54.0	1.2	2.9	19,980	262	19,718
10	2	47.8	54.0	0.6	3.0	17,190	250	16,940
11	1	52.5	70.2	0.9	3.1	18,900	183	18,717
12	2	51.5	64.8	0.15	2.7	18,540	220	18,320
13	1	52.8	64.8	0.25	2.4	18,990	200	18,790
AVERAGE		46.5	—	—	—	—	215	16,532

Although these short periods of operation at 6 gpm/ft<sup>2</sup> are not sufficient to permit a recommendation of the higher loading rates filtration, they do indicate that acceptable performance can be achieved at such rates and that they deserve further consideration prior to full scale design. Pre-ozonation had beneficial effect on the filtration process, and higher loading rates were particularly effective under these circumstances.

### GRANULAR ACTIVATED CARBON ADSORPTION

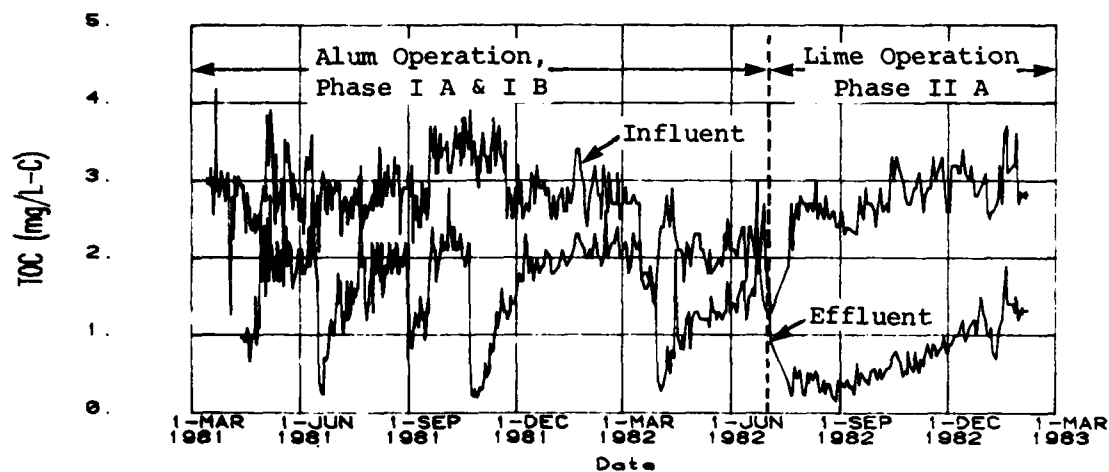
Adsorption on granular activated carbon (GAC) was included as a treatment process to remove naturally occurring and synthetic organic chemicals. Because the Potomac River estuary is an unprotected drinking water source and subject to contamination, the GAC would serve as a barrier in preventing the passage of undesirable organic chemicals into the finished water. Data presented in this section describe the ability of the lignite based ICI 816 GAC to remove TOC, TOX, and chloroform from the filtered water during Phases IA and IB. The empty bed contact time (EBCT) during both of these phases was fifteen minutes. The effects of pH, temperature, backwashing, influent water quality (TDS, and specific cations) and predisinfection on the GAC performance are also presented. Selected results from pilot scale and modeling studies are presented to better evaluate the GAC process, with respect to operating and design criteria.

#### OVERVIEW OF GAC PERFORMANCE FOR ORGANIC PARAMETERS

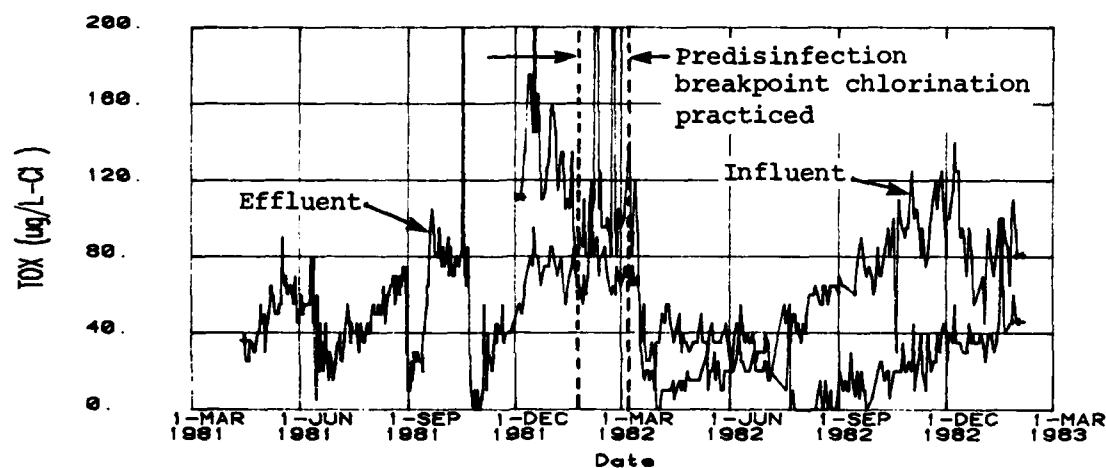
Influent and effluent time series concentration profiles are presented in Figure 7.4-7(a), (b), and (c) for TOC, TOX and chloroform, respectively. The data presented are analyses of 24-hour composite samples with one exception. Composite TOC and TOX sampling at the GAC influent was not begun until 1 December 1981, and results from grab samples have been utilized prior to this time. Note in Figure 7.4-7 that sampling ceased on 1 February for this process analysis, although plant operation continued until 16 March 1983.

The influent TOC concentration to the adsorbers ranged from 1.5 to 4.0 mg/L-C, as shown in Figure 7.4-7(a). During Phase I operation, five runs were made with various combinations of virgin and regenerated carbon. Run 1 contained two columns of virgin ICI 816 carbon and Runs 4 and 5 contained two columns of freshly regenerated carbon. For Runs 2 and 3, the exhausted lead column was removed from service, the lag column became the lead and a column of virgin carbon was placed in the lag position. Figure 7.4-7(a) shows the GAC effluent TOC values for the five runs in Phase IA and IB. Results for Phase IIA are also shown for the sake of comparison and will be discussed in Chapter 8.

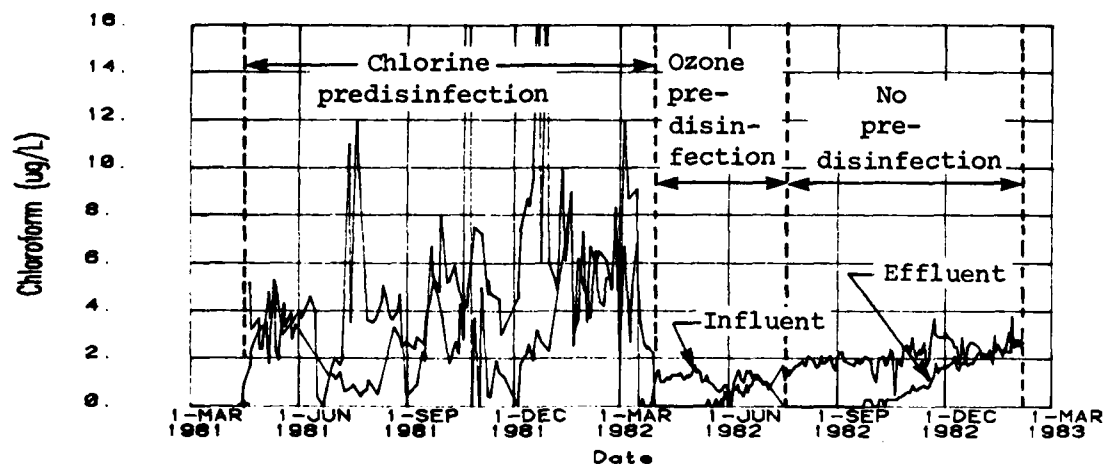
The treatment objective was set at an arbitrary value of 2.0 mg/L TOC, as previously discussed in Section 1 of this chapter. In practice, a column run was ended after the TOC averaged at least 2.0 mg/L. Run 4 was allowed to exceed this criterion so that fresh regenerated carbon would be available when ozone predisinfection was used in Phase IB.



(a) TOC



(b) TOX



(c) Chloroform

GAC INFLUENT AND EFFLUENT  
TOC, TOX AND CHLOROFORM  
(PHASES I A, I B AND II A)  
FIGURE 7. 4-7

Figure 7.4-7(b) shows TOX values for these same time periods. During the winter of 1981 and 1982, high levels of ammonia were present in the influent water. In February 1982, predisinfection breakpoint chlorination was practiced, resulting in peak concentrations of TOX exceeding 200  $\mu\text{g/L-Cl}$ . Despite the fact that the GAC columns were exhausted with respect to TOC at this time, TOX effluent concentrations remained steady, averaging 90  $\mu\text{g/L-Cl}$  or less. The reduction in influent TOX values when ozone was used as a predisinfectant is quite evident.

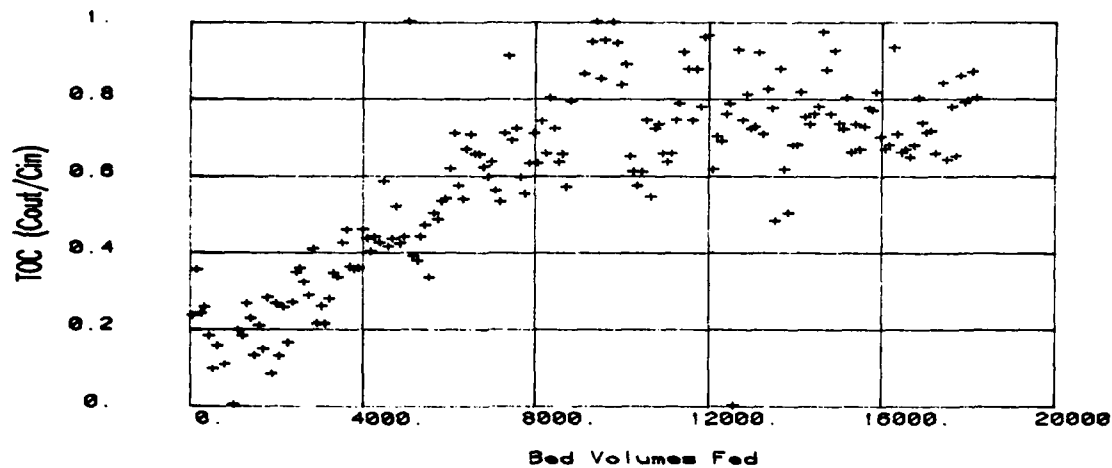
Influent chloroform concentrations were variable, ranging from 1 to 21  $\mu\text{g/L}$  during the period of chlorine predisinfection, as shown in Figure 7.4-7(c). When ozone was used as the predisinfectant, influent concentrations were nearly constant at approximately 2 to 3  $\mu\text{g/L}$ .

## REMOVAL PERFORMANCE FOR SELECTED PARAMETERS

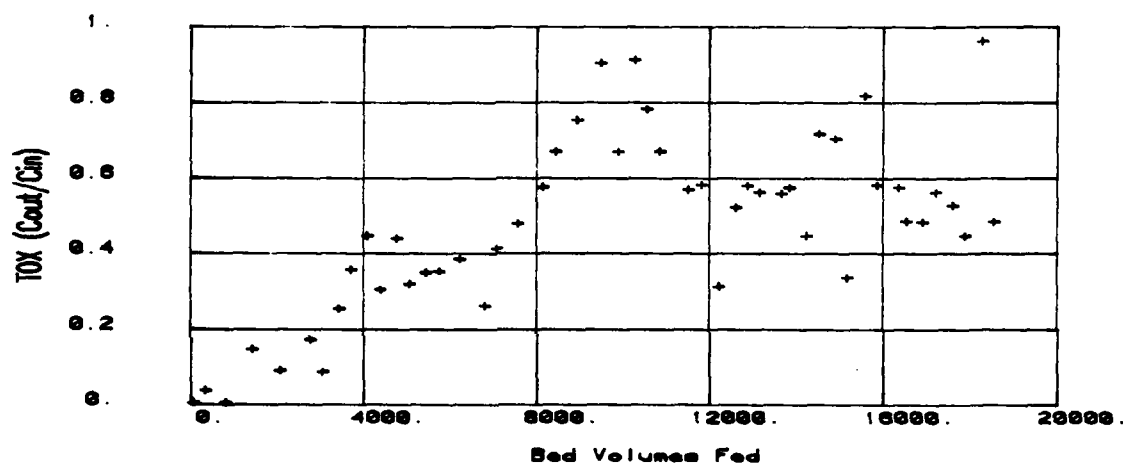
To better evaluate the removal performance of TOC, TOX and chloroform on virgin carbon, pilot column data collected during Phase I operation was evaluated. This was done because of the lack of influent TOX data for the entire time period, as previously mentioned. Because the plant-scale carbon was no longer conveniently available, pilot data are based on HD-4000, an ICI lignite carbon similar to that used at plant-scale (ICI 816), but of slightly smaller mesh size (see Chapter 10).

The removal performance for TOC, TOX and chloroform are presented in Figure 7.4-8(a),(b), and (c), respectively. In these figures, data are plotted in terms of bed volumes fed (BVF) versus the effluent concentration ( $C_{\text{out}}$ ) divided by the influent concentration ( $C_{\text{in}}$ ). This ratio represents the fraction of influent concentration remaining after treatment. TOC and TOX reach total exhaustion at the same time, approximately 9,000 to 10,000 BVF. TOC shows an immediate breakthrough, presumably due to a non-adsorbable fraction of TOC passing through the column. In a detailed analysis of the pilot column work, presented in Chapter 10, the non-adsorbable TOC concentration was estimated to be 0.4 mg/L. TOX removal of fifty percent or more occurred up until 8,000 BVF compared to 6,000 BVF for fifty percent removal of TOC.

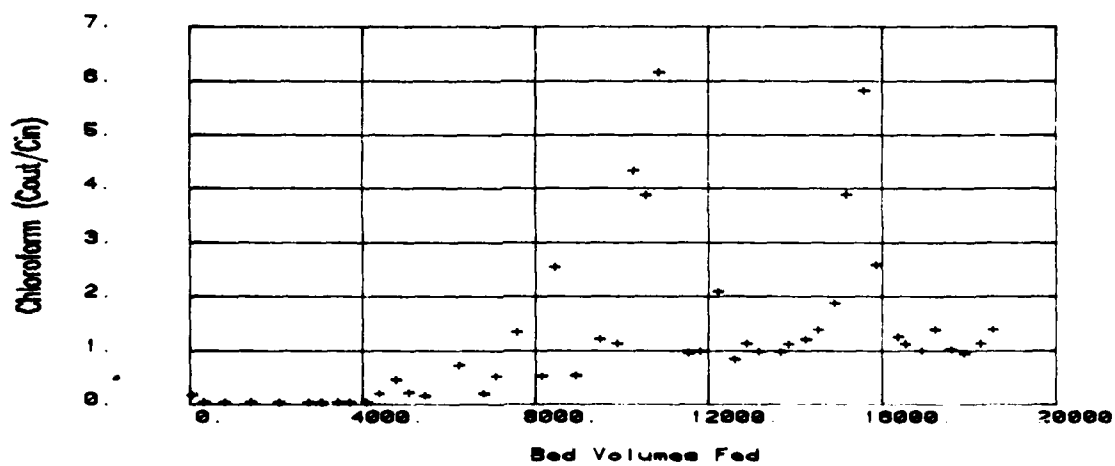
The capacity of GAC for chloroform adsorption was slightly less than for TOC or TOX. Complete exhaustion for chloroform in the pilot columns occurred (Figure 7.4-8(c)), between 7,000 and 10,000 BVF. Unlike TOC and TOX, chloroform levels in the GAC effluent after exhaustion exceeded influent concentrations. Examination of the plant scale data in Figure 7.4-7(c) reveals that this also occurred in the full-scale plant adsorbers. The fact that the effluent exceeded the influent may have been caused by two factors, 1) desorption of chloroform when the influent concentration decreased (the influent chloroform concentration was highly erratic, due mainly to the predisinfection process), and 2) displacement of previously adsorbed chloroform by stronger adsorbing compounds (competitive adsorption).



(a) TOC



(b) TOX



(c) Chloroform

REMOVAL PERFORMANCE FOR TOC, TOX AND  
CHLOROFORM ON HD-4000 CARBON  
(PHASE I PILOT DATA)  
FIGURE 7. 4-8

The concentrations of chloroform in the effluent were low compared to the THM standard of 100 µg/L, however, and thus the effects of desorption were not a problem in the finished water.

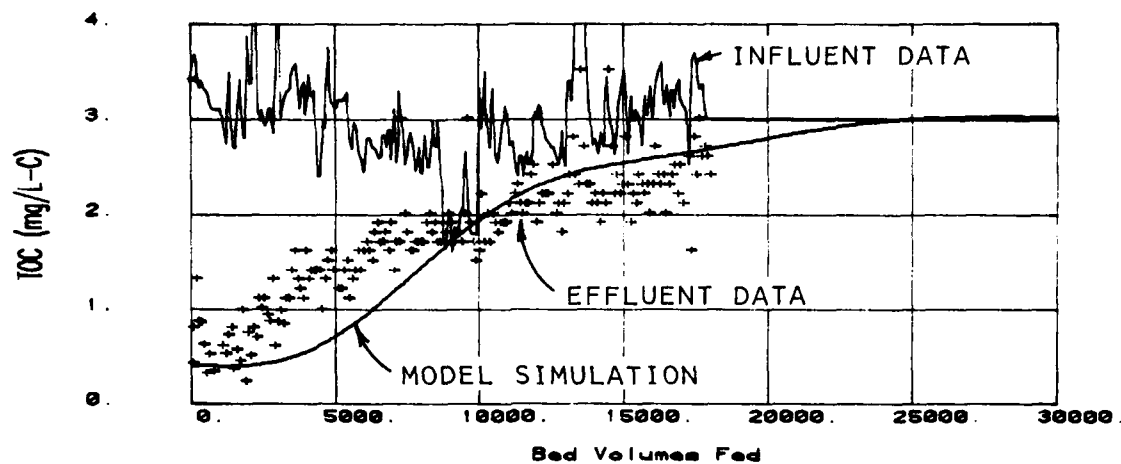
Based upon these results, the selection of TOC as a surrogate parameter for TOX breakthrough would be a conservative choice. It would not be a conservative choice for certain small volatile SOC's such as chloroform. Monitoring for SOC's would be recommended for identifying unusually high levels of SOC's which might cause an increase in regeneration frequency for the GAC adsorbers.

#### CARBON USAGE RATE

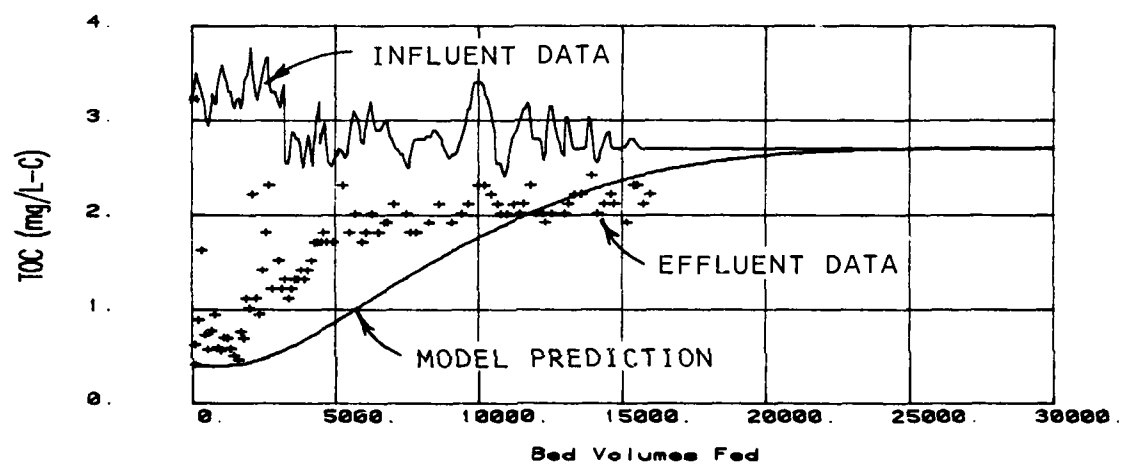
Estimates of capital and operating costs are made in Chapters 10 and 11. Carbon adsorption represents a major percentage of the total costs, with thermal regeneration of the GAC comprising most of the operating expense of the GAC process. During Phase I, over 46,000 lbs of "fresh" carbon were used to treat the water. This includes both the virgin and regenerated carbon used, and represents a carbon usage rate of 250 lbs/MG. However, a full-scale plant GAC process would probably not be designed nor operated the same as the EEWTP for reasons discussed in Chapters 10 and 11. Therefore, the costs associated with the carbon usage rate experienced at the EEWTP could be misleading. A major effort was therefore undertaken with the intent of optimizing the process to reduce capital and O&M costs. Chapter 10 summarizes the work and presents the findings.

As part of this work, the Homogenous Surface Diffusion Model (HSDM) was used. The HSDM was calibrated using bench and pilot scale data and verified by successfully predicting the effluent concentration history profiles for the plant scale adsorbers. The pilot column run the model was calibrated to fit is shown in Figure 7.4-9(a). The EBCT was fifteen minutes. The verification run is shown in Figure 7.4-9(b), with the same EBCT. The fit of the HSDM prediction to the plant data was as good as the fit to the pilot data, in spite of the fact that the pilot column used HD 4000 carbon, whereas the plant carbon was ICI 816. Both carbons are manufactured by ICI, with the major difference between the carbons being the average particle size. The HSDM accounted for the difference in particle size, but assumed all other parameters to be the same.

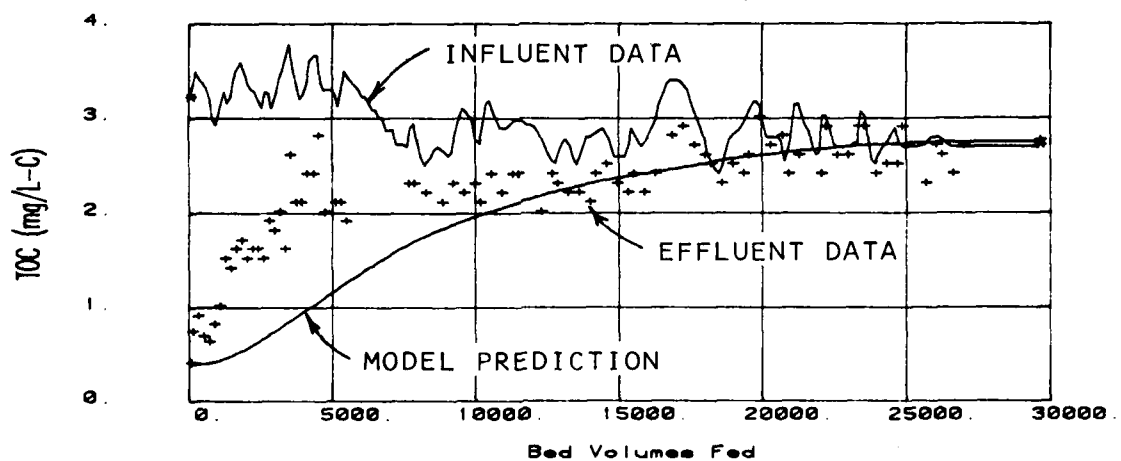
The utility of a verified model is that it can be used to predict effluent breakthrough profiles for columns with different design parameters. Carbon usage rates are calculated in Chapter 10 from HSDM predictions for various empty bed contact times. As a further test of the ability of the HSDM to predict plant scale data, a prediction of the lead column TOC breakthrough was made. This is presented in Figure 7.4-9(c). Although model predictions are initially low, the breakthrough to 2 mg/L at approximately 11,000 bed volumes was successfully predicted. This successful prediction is significant because it is for an EBCT of 7.5 minutes, and the model was calibrated based on a column with an EBCT of fifteen minutes.



(a) HSDM model calibration using pilot column data  
15 min. EBCT.



(b) HSDM verification with plant data,  
15 min. EBCT.



(c) HSDM model prediction of plant data with  
7.5 min. EBCT.

# HSDM MODELING RESULTS (PHASE I) FIGURE 7. 4-9



## PROCESS PROBLEMS AND RELIABILITY

The adsorption capacity of GAC for any chemical or group of chemicals is dependent on temperature, and for many compounds, capacity is also a function of pH and background chemicals. Humic substances for instance have been shown to be more adsorbable as the pH decreases (Lee, 1980; McGreary and Snoeyink, 1977), and in the presence of soluble aluminum (Lee, 1980). Under actual operating conditions, pH, temperature and coagulant dose cannot always be held constant, or may need to be changed in response to changes in influent water quality. In theory, variations in these parameters could lead to a reduction in the capacity of GAC for compounds already adsorbed causing desorption of previously adsorbed compounds. Desorption of compounds leads to effluent concentrations exceeding those in the influent, with the degree of difference dependent upon the state of exhaustion of the GAC and the quantity of the chemical adsorbed.

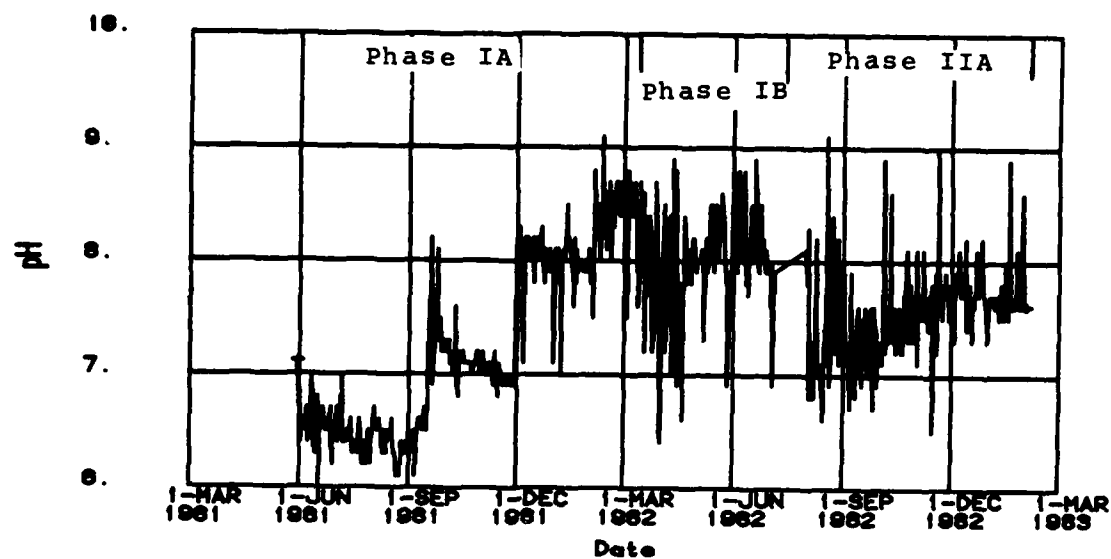
During Phase I operation of the EEWTP, variations in pH, temperature and coagulant dose were experienced. Time series plots of pH and temperature in GAC influent waters are presented in Figures 7.4-10 and 7.4-11. Calcium, magnesium and aluminum concentrations are given in Figure 7.4-12. These cations can influence adsorption efficiency. For reference, a time series plot of TOC is given in Figure 7.4-13.

The average pH of the influent to the GAC contactors varied during Phase I from 6.5 to 8.0, as shown in Figure 7.4-10. Temperature varied from 7 to 30°C. Alum was used as the primary coagulant for Phase I and aluminum concentrations in the GAC influent are shown in Figure 7.4-12. For plotting purposes, the concentration has been multiplied by 100. The aluminum concentration averages below 200 µg/L until 1 December 1981, and thereafter averages between 200 to 400 µg/L until the end of Phase I in July. Lime was used for pH control during different periods of Phase I, but the calcium concentration remained relatively stable during this time period. The background concentration of magnesium showed little variation and is shown for comparison.

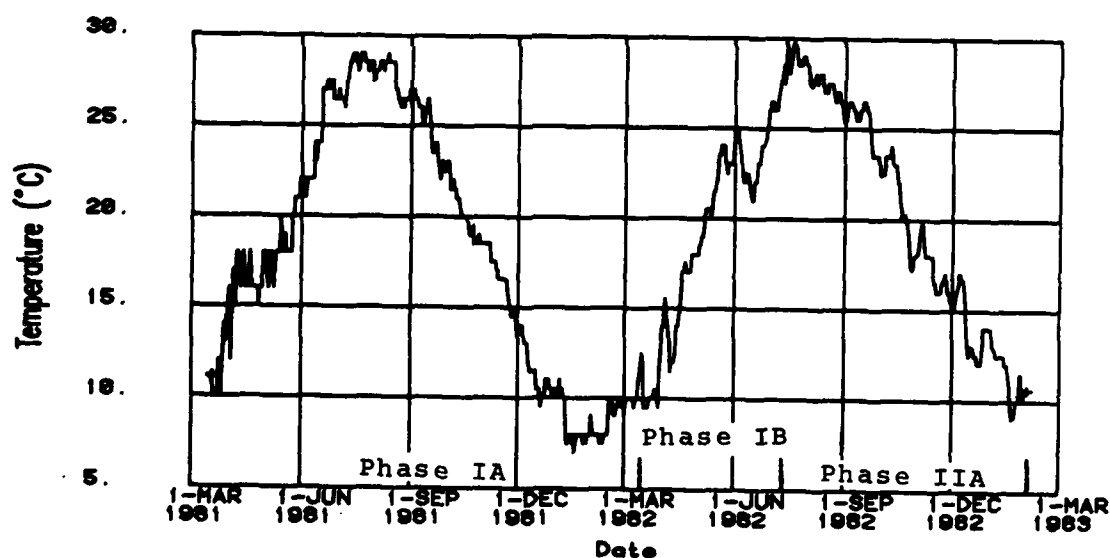
Despite the changes in GAC influent water quality noted above, the removal performance for TOC was largely unaffected. Sustained periods where the effluent exceeded the influent were not encountered. Undoubtedly, pH, temperature, and various cations can have an effect on adsorption, but their effect on the GAC operation was minor with respect to TOC. However, one thing that did seem to have noticeable impact on the breakthrough of TOC was backwashing, as discussed below.

## EFFECT OF BACKWASHING ON GAC PERFORMANCE

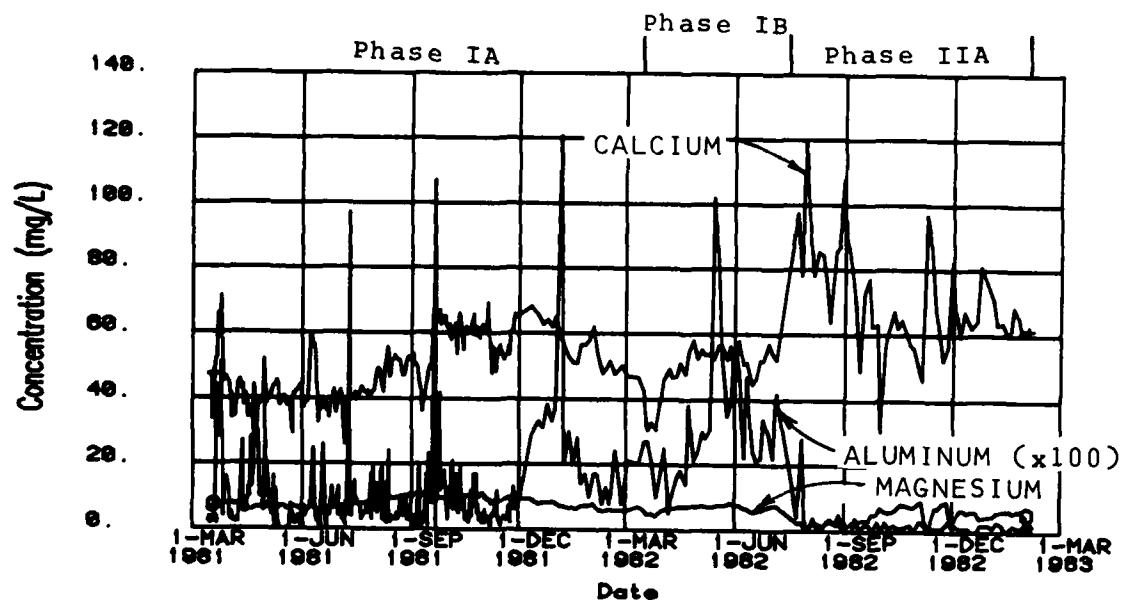
As discussed in Section 1 of this chapter, in early November 1981 the arbitrary five day GAC backwash criterion was dropped leaving excessive headloss and/or oxygen depletion as the remaining backwash initiation criteria. This was done to observe the effect of decreased bed disturbance (as a result of fewer backwashes) on TOC removal performance. It is postulated that the adsorption



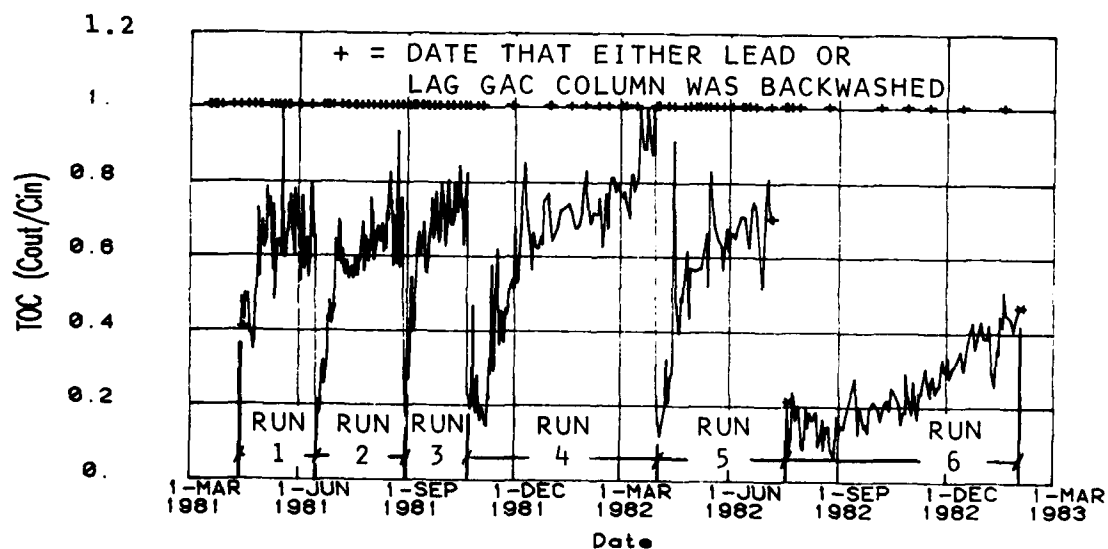
**pH OF GAC INFLUENT WATER  
(PHASES IA, IB AND IIA)  
FIGURE 7. 4-10**



**TEMPERATURE OF GAC INFLUENT WATER  
(PHASES IA, IB AND IIA)  
FIGURE 7. 4-11**



**Ca, Mg AND Al IN GAC INFLUENT WATER**  
**FIGURE 7. 4-12**



**GAC REMOVAL PERFORMANCE FOR**  
**TOC WITH BACKWASH DATES**  
**FIGURE 7. 4-13**

wave or zone of active transport is disturbed during backwashing, ultimately causing faster TOC breakthrough and, thus, increasing the carbon usage rate.

This change in procedure caused backwashing frequency to be reduced by approximately 75 percent. However, no significant effect on TOC breakthrough or removal capacity was noted. This is illustrated in Figure 7.4-13 which shows the fractional TOC remaining and GAC backwash occurrence on a time scale. (The increased variability and resolution of the TOC fraction remaining through November 1981 is a result of a change in sample type and frequency, as discussed earlier in this section, and not backwashing.)

Although these results suggest that reducing the frequency of backwashing did not significantly effect TOC removal, considerable economic and operational advantages can be realized by such a change.

### MICROBIOLOGICAL ACTIVITY

Total coliforms and standard plate count (SPC) were measured in the influent and effluent to the adsorbers and data are presented in Figure 7.4-14(a) and (b) for these two parameters, respectively. There was an increase in mean levels of both parameters across the GAC columns. This was not unexpected, as microbiological activity is known to occur in GAC adsorbers (Weber et al., 1978).

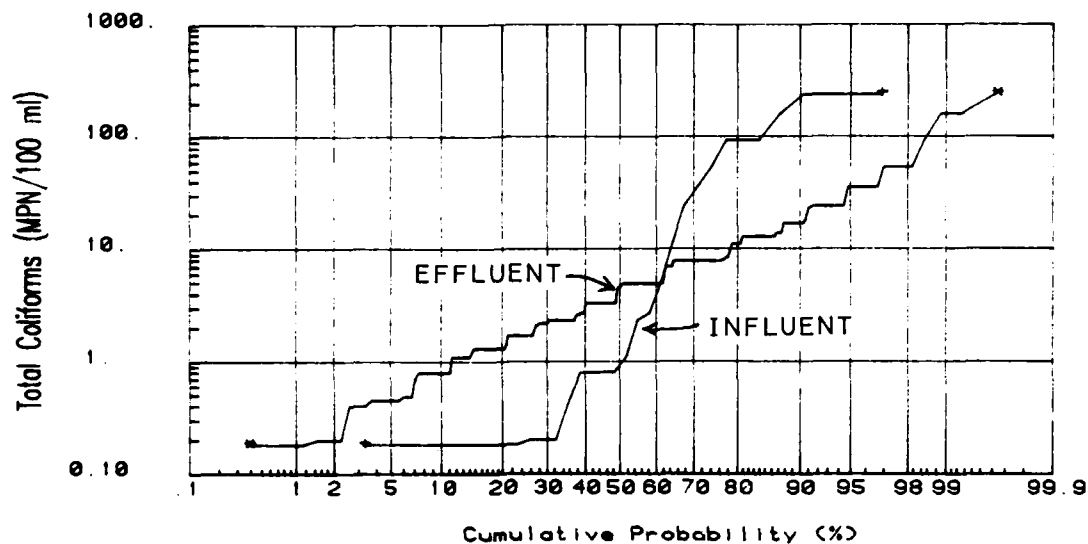
It is possible that biological activity is responsible for the apparent steady state removal of some compounds, and in particular, TOC and TOX. The plots of the pilot column TOC and TOX data, shown in Figures 7.4-8(a) and (b), are good examples of a GAC adsorber that exhibits steady state removal. After 9,000 to 10,000 BVF, the ratio of effluent concentration to influent concentration reached a plateau of approximately 0.8. Steady state removal averaging twenty percent continued through 18,000 BVF, at which time the run was terminated. Although coliform and SPC were not measured on the pilot column, there is little doubt that they were present in the columns. It is not clear, however, whether or not the apparent steady state removal was due in part or wholly to microbiological activity, or some other cause such as slow diffusion of adsorbate into the micropores of the carbon.

### COMPARISON OF THE PRETREATMENT METHODS

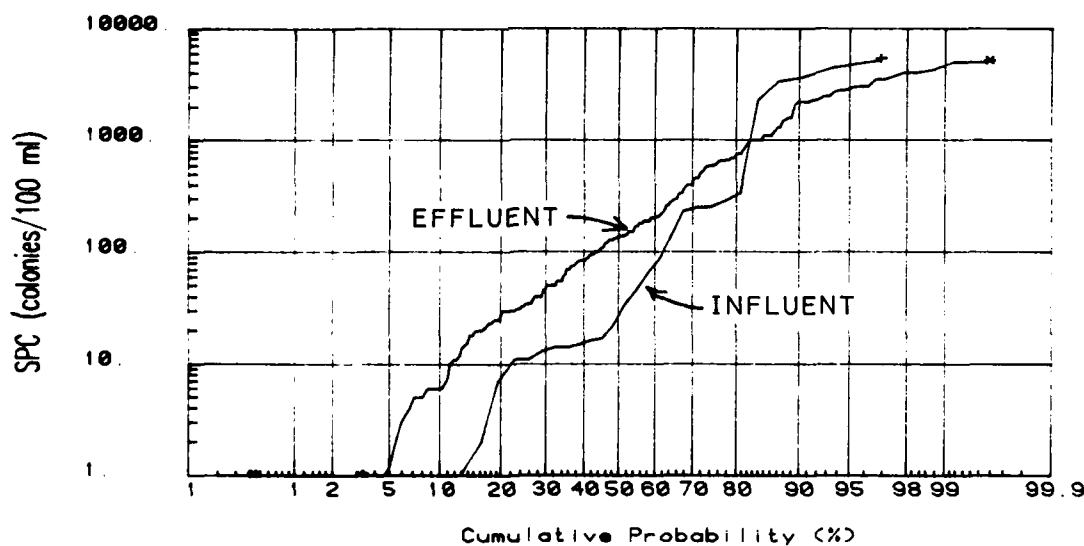
The removal performances of Runs 4 and 5 are shown in Figure 7.4-15. Both runs used regenerated carbon. Chlorine was used as the predisinfectant in Run 4, and ozone in Run 5. The data plotted represents fifteen minutes of empty bed contact time, and shows the oxidant used had no apparent impact on the removal of TOC under the conditions tested.

### COMPARISON OF VIRGIN AND REGENERATED CARBONS

The removal performances for TOC on virgin (Run 1) and regenerated carbon (Run 4) are presented in Figure 7.4-16. The removal performance of the regenerated carbon compares favorably with the virgin carbon. However, as

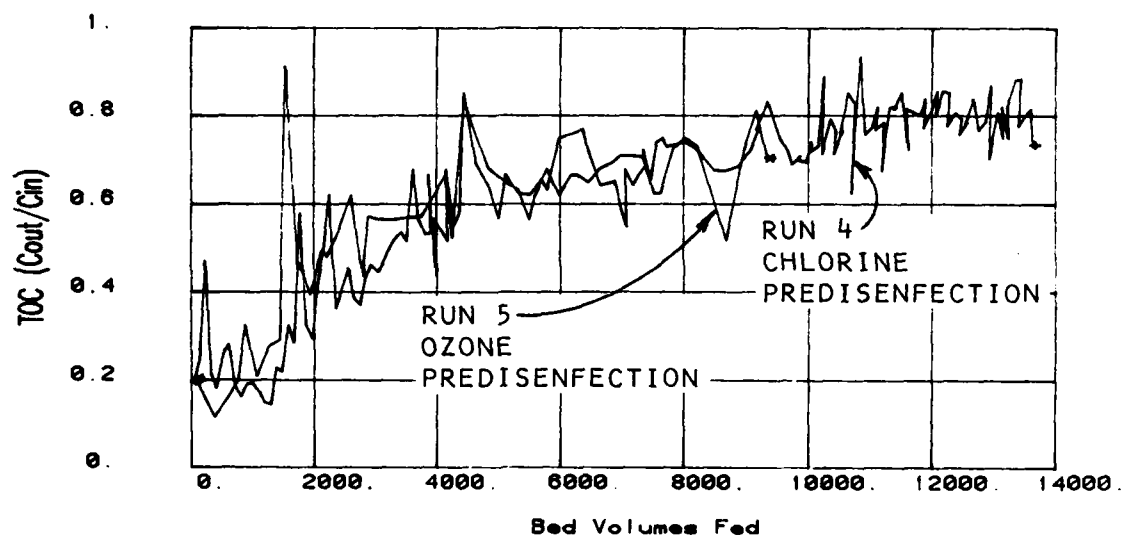


(a) Total Coliforms

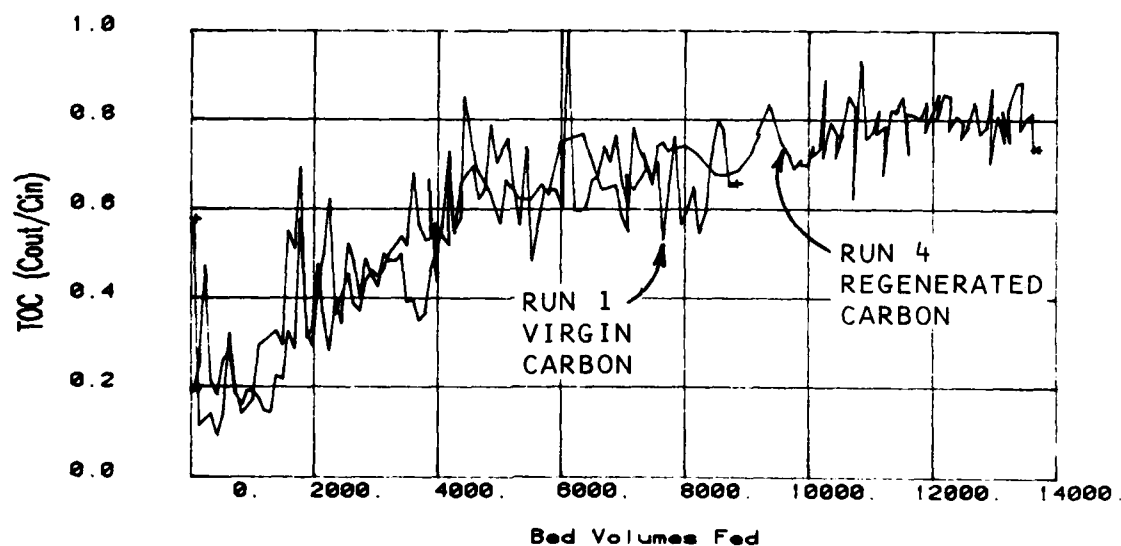


(b) Standard Plate Count

PROBABILITY DISTRIBUTIONS OF TOTAL COLIFORMS  
AND SPC IN GAC INFLUENT AND EFFLUENT  
(PHASES I A AND I B)  
FIGURE 7. 4-14



**COMPARISON OF CHLORINE AND  
OZONE PREDISINFECTION ON  
TOC REMOVAL PERFORMANCE  
FIGURE 7. 4-15**



**COMPARISON OF VIRGIN AND  
REGENERATED CARBON ON TOC REMOVAL  
FIGURE 7. 4-16**

## Process Analysis

stated previously, it was believed that the virgin carbon may have lost some of its capacity prior to its use in Run 1. This belief is based on the fact that the carbon was stored wet in the adsorber columns and storage tanks for at least one year before being used. Secondly, a corrosion problem was discovered in at least one of the columns where the carbon was stored. Therefore, it is difficult to say conclusively that virgin and regenerated GAC will perform the same, despite the apparently similar results of Figure 7.4-16.

### DISINFECTION

During both Phases IA and IB, final disinfection was achieved in a serpentine flow reactor using free chlorine as the disinfectant. Free chlorine disinfection was the final treatment barrier at the EEWTP for removal of microbiological contaminants which might be present in the GAC effluent.

The process objectives and operational characteristics of the disinfection process were presented in Section 1 of this chapter. Key design and operational criteria include applied chlorine dose, free residual leaving the treatment plant, hydraulic detention time in the contact basin, and design of the contact basin.

Both the contact basin design and the hydraulic detention time were fixed during Phase I, while the free chlorine residual was varied to determine the required residual to achieve satisfactory finished water quality with respect to microbiological contaminants.

The efficiency of disinfection depends on the characteristics of the disinfectant, the contact time, the residual concentration, the contactor design, and finally the characteristics of the target organism (i.e., bacteria, virus or other microorganism).

The characteristics of the disinfectant depend on several water quality parameters including pH, temperature, and presence of oxidant demanding substances, e.g., ammonia or organic carbon.

As discussed in Chapter 9, Section 6, the frequency of coliform isolations in the EEWTP finished water was higher than the local water treatment plants during Phase IA. Even though the EEWTP met the total coliform MCL, the overall levels in the finished water during Phase IA were higher than NAS criteria (NAS, 1977) for potable reuse and at various times above the AWWA operational goal of 0.1 MPN/100 ml. Total coliforms in Phase IB finished water met the MCL and NAS criteria but were still higher than the local WTPs. The relatively poor performance during Phase IA was largely attributable to the first several months of operation, as described below.

### PHASE IA DISINFECTION

Changes in temperature, pH, ammonia and the concentration of microorganisms in the process influent affected the efficiency of disinfection using free chlorine, the primary operational mode during Phases IA and IB. The possible

## Process Analysis

impact of some of these parameters on the chlorine disinfection process is discussed below.

### Total Coliforms

Figure 7.4-17 is a time series plot of total coliform levels in the Phase IA final carbon column effluent, which is the influent feed to final disinfection, and the EEWTP finished water. Two particular periods of elevated coliform levels in the finished water were observed. These were from the initiation of operation in March 1981 through June 1981, and October through December 1981. Forty-five percent of the positive total coliform samples detected during all of Phase IA were observed between 16 March 1981 and 1 July 1981. The geometric mean concentration during this period was 0.08 MPN/100 ml compared to 0.03/100 ml for all of Phase IA. When the March through July period is excluded from the statistic evaluation, the remainder of Phase IA had a slightly lower geometric mean, 0.02/100 ml, but more importantly met the NAS potable reuse criteria as discussed in Chapter 9, Section 6.

Time series plots of total coliforms, free chlorine residual (Figure 7.4-18) and total chlorine residual (Figure 7.4-19) in Phase IA finished water do not indicate a completely clear relationship between coliform breakthrough and residual concentration. However, free and total residuals were generally lower during the first period of high coliform concentrations (March through June). During this period the mean free and total residuals were 1.3 mg/L and 1.6 mg/L, respectively. After 1 July the mean residuals were 1.7 mg/L and 2.2 mg/L. Overall Phase IA chlorine residuals were 1.6 mg/L free and 2.0 mg/L total.

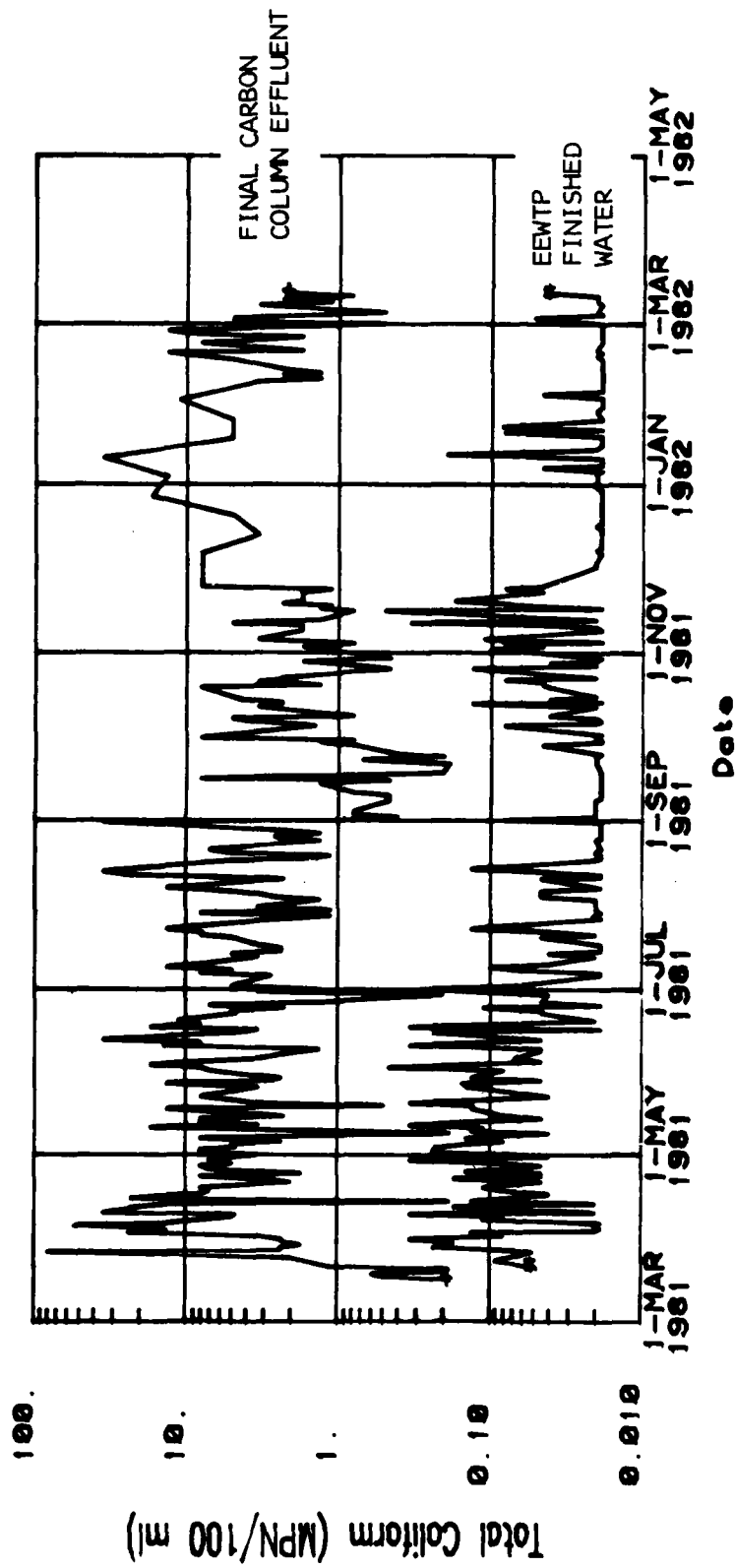
Table 7.4-4 summarizes mean residual concentrations, geometric mean total coliform concentrations and total coliform geometric mean log removal through the disinfection process during the pre- and post 1 July 1981 periods and all of Phase IA.

TABLE 7.4-4  
IMPACT OF CHLORINE RESIDUAL ON DISINFECTION  
OF TOTAL COLIFORMS  
(Geometric Means)

	16 March - 30 June 1981	1 July 1981 - 16 March 1982	16 March 1981 - 16 March 1982
Free Chlorine (mg/L)	1.3	1.7	1.6
Total Chlorine (mg/L)	1.6	2.2	2.0
G.M. Total Coliform (MPN/100 ml)	0.08	0.02	0.03
G.M. Log Removal <sup>1</sup>	1.8	2.1	2.0

1.  $\log_{10}$  (GAC effluent geometric mean  $\div$  finished water geometric mean).





TOTAL COLIFORMS IN EEWTP GAC EFFLUENT  
AND FINISHED WATER  
(PHASE 1A)  
FIGURE 7. 4-17

## Process Analysis

During the latter part of January 1982 and into February, the free chlorine residual dropped off sharply because of high ammonia concentrations entering the EEWTP from the Blue Plains nitrified effluent (Figure 7.4-18). The total residual, mostly in the combined form, increased during this period reaching a maximum of 7.2 mg/L (Figure 7.4-19). The applied chlorine dosage was raised in order to achieve breakpoint chlorination. Although the free residual was generally below 1 mg/L, samples from this period had very few coliforms in the finished water compared to previous IA sampling. Combined chlorine, a weaker disinfectant than free chlorine, was at high enough concentrations to effectively kill the coliforms.

### Standard Plate Count

Figure 7.4-20, a time series plot of bacterial SPC in the finished water, shows that sustained peaks of high plate counts occurred from July through October 1981, a time during which total coliforms were at their lowest levels in the finished water. Total coliform and SPC disinfection do not appear to parallel each other.

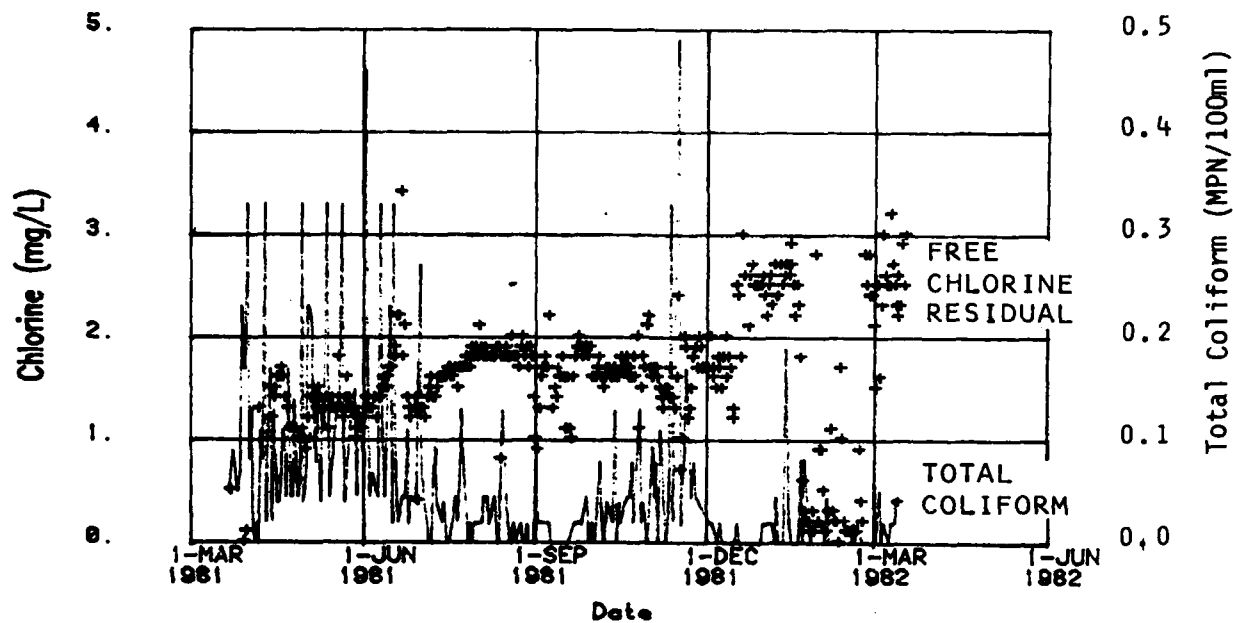
## PHASE IB DISINFECTION

### Total Coliforms

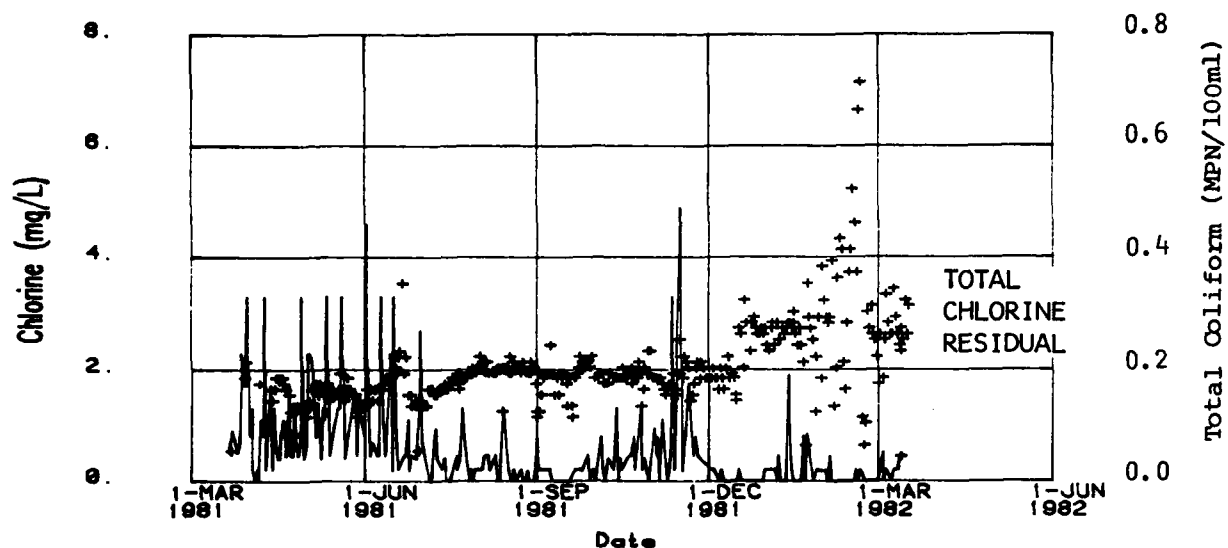
There was a noticeable improvement in Phase IB final disinfection compared to Phase IA. Only 25 percent of the samples analyzed in Phase IB were positive for total coliforms as opposed to 65 percent in Phase IA. Geometric mean concentrations were 0.03/100 ml and 0.008/100 ml for Phases IA and IB, respectively. The improvement was primarily due to an increase in applied chlorine dosage which resulted in mean residuals of 2.4 mg/L and 2.8 mg/L free and total chlorine as opposed to 1.6 and 2.0 mg/L in Phase IA.

### Standard Plate Count

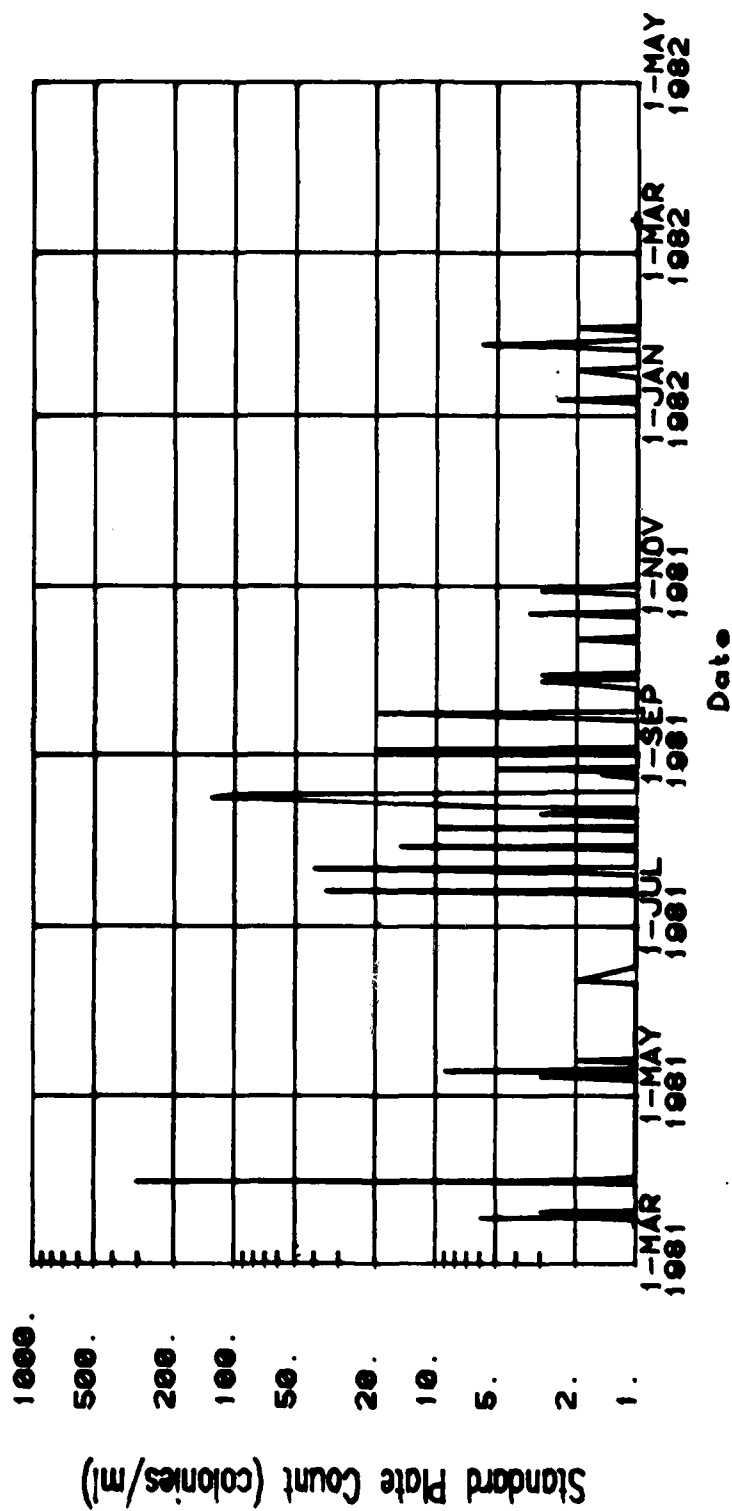
The increase in residual disinfectant in Phase IB did not appear to have much additional effect on bacterial removal, as measured by SPC. SPC levels during both phases were quite low.



**FINISHED WATER  
FREE CHLORINE  
RESIDUAL AND TOTAL COLIFORMS  
(PHASE IA)  
FIGURE 7. 4-18**



**FINISHED WATER  
TOTAL CHLORINE RESIDUAL AND  
TOTAL COLIFORMS  
(PHASE IA)  
FIGURE 7. 4-19**



SPC IN PHASE IA EEWTP FINISHED WATER  
FIGURE 7. 4-20

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## CHAPTER 8

### PLANT PERFORMANCE - LIME PHASE

As discussed in the introduction to Chapter 7, the objectives of the plant performance chapters are to provide information describing the treatment facilities, how they were operated and how they performed with respect to the water quality parameters monitored. This chapter covers Phase II of plant operations. Section 1 describes the process configuration used and provides design and operating information. Section 2 provides data describing overall plant performance. Section 3 traces the fate of selected parameters through the treatment plant, and Section 4 examines the major water treatment processes used and discusses relevant operational and performance issues.

The Phase II period of operation was divided into parts A and B. Phase IIA began on 16 July 1982 and terminated on 1 February 1983. Phase IIB covered the period from 1 February 1983 until the EEWTP ceased operation on 15 March 1983. The results from Phase IB can be found in Appendix G, Section 4.

## SECTION 1

### PROCESS OVERVIEW

#### PROCESS CONFIGURATION

The process combination used in Phase II consisted of chemical clarification with lime as primary coagulant and ferric chloride as coagulant aid, recarbonation with commercial carbon dioxide, dual media gravity filtration, granular activated carbon adsorption, primary disinfection with ozone and residual disinfection by chloramination. This process flow schematic is illustrated in Figure 8.1-1.

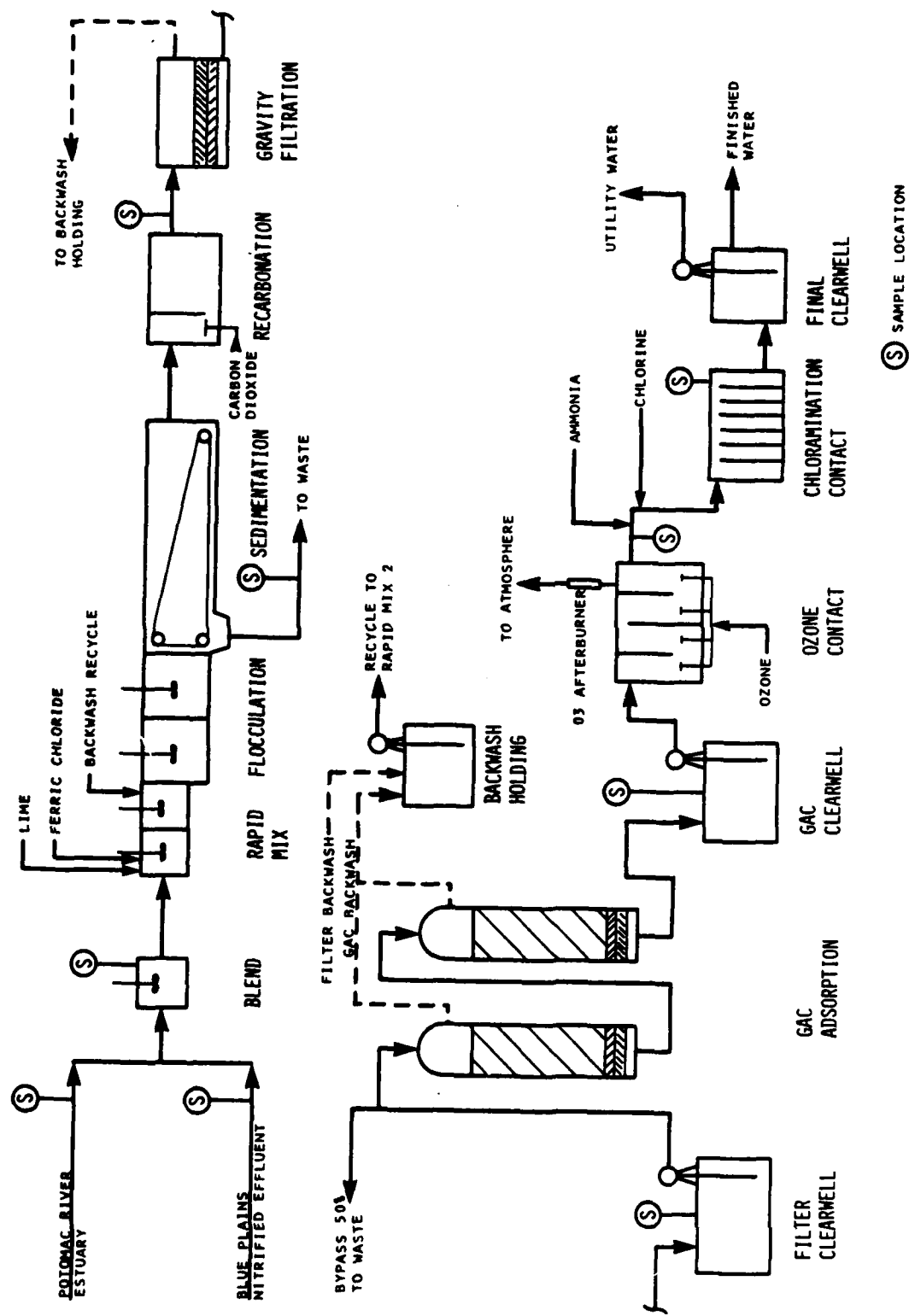
This process combination was selected in an effort to produce the highest quality water possible and to minimize the problems associated with Phase I operation. Lime was chosen as the primary coagulant because it offered several important benefits including improved metals removal, partial disinfection, less corrosive finished water, and potentially better TOC removal and pretreatment for GAC adsorption. Bituminous carbon was selected to replace the lignite based carbon and the empty bed contact time was doubled to enhance TOC removal and carbon usage, and to provide an improved barrier against influent synthetic organic chemical spikes.

Ozone was selected as the primary disinfectant in an attempt to achieve better total coliform kills and to reduce the odor of the finished water. Chloramines were chosen as the residual disinfectant because of their persistence and effectiveness as a bactericide with sufficient contact time. This disinfection arrangement also produced fewer chlorinated organic compounds than free chlorine. Each process used in Phase II is examined in greater detail in the following section.

#### UNIT PROCESS DESCRIPTIONS

This section provides physical descriptions and details concerning the operational history of the treatment processes used during Phase IIA. Many of the processes used in Phase II were also used during Phases IA and IB. These included rapid mix, flocculation, sedimentation and gravity filtration. Detailed descriptions and design criteria of these processes can be found in Chapter 7 and Appendix D of this report. Information regarding the operating history of these processes and the ones unique to Phase II of operation are presented in this section. A summary of operating conditions and process design criteria is presented in Table 8.1-1.





**EEWTP PROCESS FLOW SCHEMATIC  
(PHASE II)**  
**FIGURE 8. 1-1**

# Process Overview

TABLE 8.1-1  
OPERATIONS SUMMARY FOR PHASE IIA  
(16 JULY 1982 TO 1 FEBRUARY 1983)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Potomac River Estuary Pump Station	<p><u>Intake Pumps</u> Number: 2 Type: non-clog centrifugal Flow: 22 L/S (350 gpm) @ 20.4 m (67 ft) TDH</p> <p><u>Discharge Piping</u> Diameter: 0.2 m (8 in) Material: polyethylene</p>	<p>Operating period: Phase II</p> <p>Average daily flow: 955 m<sup>3</sup>/d (0.255 mgd)</p> <p>When out of service, used 100% nitrified effluent</p>	<p>% Downtime: &lt;1</p> <p>Causes: power failure</p>
Blue Plains Nitrified Effluent Pump Station	<p><u>Intake Pumps</u> Number: 4 Type: non-clog centrifugal Flow: 22 L/S (350 gpm) @ 26 m (85 ft) TDH</p> <p><u>Discharge Piping</u> Diameter: 0.2 m (8 in) Material: polyethylene</p>	<p>Operating period: Phase II</p> <p>Average daily flow: 931 m<sup>3</sup>/d (0.249 mgd)</p> <p>When out of service, used 100% Potomac estuary water</p>	<p>% Downtime: 12</p> <p>Causes: Broken discharge line Power failure</p>
Rapid Mix	<p>Number: 2 in series Volume ea.: 1.4 m<sup>3</sup> (49 ft<sup>3</sup>) Detention time: 1 min each Mixing energy, G = 400 sec<sup>-1</sup></p>	<p>Operating period: Phase II</p> <p>Addition of lime in rapid mix 1</p> <p>Addition of FeCl<sub>3</sub> in rapid mix 1</p> <p>4 L/m carrier water added to each</p>	<p>% Downtime: Rapid Mix No. 1: &lt;1 Rapid Mix No. 2: &lt;1</p> <p>Causes: Maintenance Replace motors</p>
Coagulation Chemical Addition	<p><u>Primary coagulant: lime</u> (slaked quicklime, fed to process in slurry form)</p> <p><u>Coagulant aid: ferric chloride</u> 30% solution - FeCl<sub>3</sub></p>	<p>Operating Period: Phase II</p> <p>Average lime dose: 80 mg/L CaO</p> <p>Average ferric chloride dose: 2 mg/L</p> <p>Process controlled by pH maintenance in flocc tank no. 1</p> <p>pH ranges used: 10.2 to 11.4</p>	<p>% Downtime: (brief interruptions)</p> <p>Causes: Lime feed system</p>
Flocculation	<p>Number of stages: 2 Volume ea.: 26.5 m<sup>3</sup> (1,800 cu ft)</p> <p>Det. time @ avg flows ea: 20 min</p> <p><u>Mixers</u> Number per stage: 2 Type: variable speed, pitched Blade turbine Speed range: 30 to 100 rpm</p>	<p>Operating period: Phase IIA</p> <p>Tapered operation</p> <p>Stage 1 avg rpm: 70</p> <p>Stage 2 avg rpm: 35</p>	<p>% Downtime: 0</p>

# Process Overview

TABLE 8.1-1 (Continued)

## OPERATIONS SUMMARY FOR PHASE IIA (16 JULY 1982 TO 1 FEBRUARY 1983)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
Sedimentation	<p>Detention time: 4.5 hours</p> <p>Surface loading rate: 19.2 m<sup>3</sup>/m<sup>2</sup>-d (470 gpd/ft<sup>2</sup>)</p> <p>Weir loading rate: 18 m<sup>3</sup>/m-d (6,250 gpd/ft)</p> <p>Sludge collection: Longitudinal cross collectors</p> <p>Sludge Pumps</p> <p>Number: 2</p> <p>Type: progressive cavity</p> <p>Flow: 3.2 L/S (50 gpm) @ 690 kpa (100 psi) TDH</p> <p>Motor power: 7.5 kw (10 hp)</p>	<p>Operating period: Phase IIA</p> <p>Collector mechanism on continuously</p> <p>Sludge withdrawal daily - 1 hour</p> <p>Sludge flow sampled and sent to waste</p>	<p>% Downtime: 0</p>
Single Stage Recarbonation	<p>Detention time:</p> <p>Compartment 1: 7.2 min (CO<sub>2</sub> application)</p> <p>Compartment 2: 16.6 min (holding)</p> <p>CO<sub>2</sub> source: Commercial grade liquid</p> <p>Diffusers: Coarse bubble</p>	<p>Operating period: Phase IIA</p> <p>Control: manual pH maintenance</p> <p>pH range: 7.4 to 8.0</p> <p>Average CO<sub>2</sub> dose: 230 mg/L</p>	<p>% Downtime: 0</p>
Dual Media Gravity Filtration	<p>Number: 2</p> <p>Filter area ea: 5.57 sq m (60 sq ft)</p> <p>Filtration rate:</p> <p>Avg 2 L/m<sup>2</sup>-s (3 gpm/sq ft)</p> <p>Max 4 L/m<sup>2</sup>-s (6 gpm/sq ft)</p> <p>Media</p> <p>Anthracite</p> <p>Depth: 0.5 m (20 in)</p> <p>Eff. size: 1.4 mm</p> <p>Sand</p> <p>Depth: 0.25 m (10 in)</p> <p>Eff. Size: 0.5 mm</p>	<p>Operating period: Phase IIA</p> <p>Control mode: constant rate with automatic effluent valve control</p> <p>Filtration rates: see text</p> <p>Backwash criteria: see text</p> <p>Backwash Rates</p> <p>Low: 6.8 L/m<sup>2</sup>-min (10 gpm/sq ft)</p> <p>High: 11.5 L/m<sup>2</sup>-min (17 gpm/sq ft)</p> <p>Constant surface wash during backwash cycle (completely manual)</p> <p>Backwash water recycled: see text</p>	<p>% Downtime: 0</p>
Bypass Line	<p>0.1 m (4 in) PVC line plumbed from GAC feed pumps to waste</p>	<p>Operating period: Phase IIA</p> <p>Purpose: used to waste approx. 50% of plant flow to achieve 30 min EBCT in GAC adsorption process</p> <p>Controlled manually with throttling valve</p>	<p>% Downtime: 0</p>

# Process Overview

TABLE 8.1-1 (Continued)

## OPERATIONS SUMMARY FOR PHASE IIA (16 JULY 1982 TO 1 FEBRUARY 1983)

Process	Major Design Criteria	Operating Criteria	Major Downtime and Causes
GAC Adsorption	Configurations: 2 pressure contactors in series EBCT: 15 min Surface loading rate: 3 L/m <sup>2</sup> -sec (4.5 gpm/ft <sup>2</sup> ) GAC Type: bituminous based, 12x40 mesh, Calgon F-400	Operating period: Phase IIA Column sequence: 1/3 See text for carbon specifications, backwash criteria and procedures, and exhaustion criteria	% Downtime: 0
Final Disinfection Ozone	<u>Ozone Generator</u> Type: horizontal tube, corona discharge Capacity: 36 kg/d (80 lbs/day)  (unit modified to reduce max output capacity to approx. 10 kg/d)  <u>Contactor</u> Type: 4 pass vertical serpentine Diffuser: ceramic Detention time: 22 min @ 9,500 m <sup>3</sup> /d (0.25 mgd) Offgas: thermally decomposed by after burner heater	Operating period: 8/5/82 to 2/1/83 Ozone applied in counter-current passes 1 and 3 Average O <sub>3</sub> dose: 1.3 mg/L O <sub>3</sub>  Average O <sub>3</sub> residual: 0.20 mg/L O <sub>3</sub> Range (0.03 to 0.47 mg/L-O <sub>3</sub> )	% Downtime: 10 Causes: Contact tank repair Cooling water plumbing change Ambient ozone testing Replacement of teflon tube plugs with glass dielectric tubes (see text for details)
Residual Disinfection - Chloramination	<u>Ammonia</u> Manual batching of aqua-ammonia (30% NH <sub>3</sub> -N)  Fed to process with chemical metering pump  <u>Chlorine</u> Std. gas chlorinator fed from 150 lb cylinders <u>Contact Time</u> Type: serpentine Detention Time: 110 min @ 950 m <sup>3</sup> /d (0.25 mgd)	Operating period: Phase IIA Addition: NH <sub>3</sub> then Cl <sub>2</sub> Average NH <sub>3</sub> dose: 1.5 mg/L-N  Average Cl <sub>2</sub> dose: 4.9 mg/L Average combined Cl <sub>2</sub> residual: 3.0 mg/L	% Downtime: <1 Causes: Modifications to stabilize process and facilitate measurement of ammonia application rate

Note: Mixing energies, G, are approximate

## Process Overview

### INFLUENT PUMPING AND HANDLING

An equal blend of Potomac River estuary water and unchlorinated nitrified Blue Plains effluent was achieved in over 96 percent of the Phase IIA operating period. Estuary flow was interrupted for several hours on 26 January 1983, and the Blue Plains supply was lost for a total of seven days during Phase IIA. The exact dates and causes of these interruptions are presented in Table 8.1-2 below. The table also includes a 23-day outage of the nitrified effluent supply that occurred in February 1983 during Phase IIB operation.

Figures 8.1-2 and 8.1-3 show the combined daily average influent flowrate and the percent estuary water used for Phase IIA. During the Phase II operating period, the combined influent flowrate averaged 0.504 MGD and was composed of 50.6 percent estuary water.

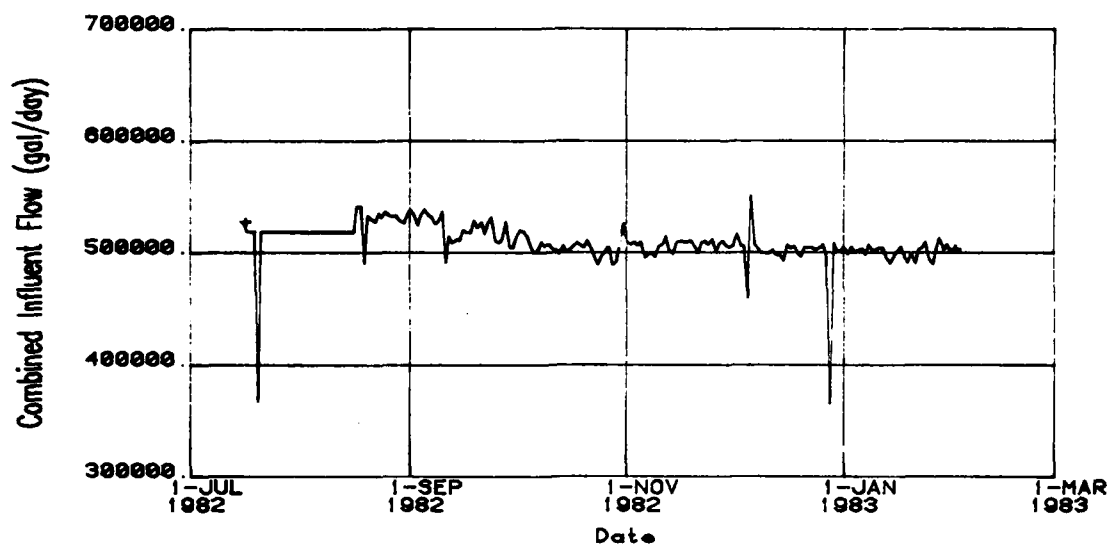
As in Phase I, influent flow was maintained at approximately 0.5 MGD with the on-line raw water as sole source during any flow interruption. Continuous influent flow was maintained throughout the entire operating period.

TABLE 8.1-2  
EEWTP INFLUENT INTERRUPTIONS PHASE II

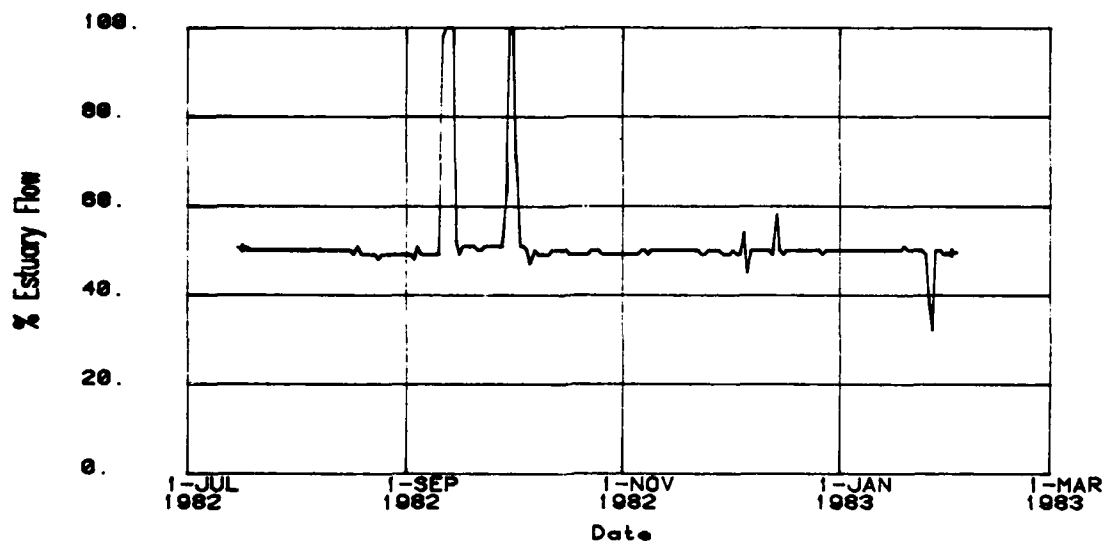
<u>ESTUARY SOURCE</u>	
<u>Dates</u>	<u>Cause</u>
1/26/83 to 1/27/83	Power Failure at Pump Station
<u>NITRIFIED EFFLUENT SOURCE</u>	
9/10/82 to 9/14/82	Broken Supply Line
9/29/82 to 10/1/82	Power Failure at Pump Station
2/1/83 to 2/23/83 <sup>1</sup>	Broken Supply Line
<u>1. Phase IIB</u>	

### CHEMICAL CLARIFICATION

The objectives, process facilities, and hydraulic detention times used in the chemical clarification process during Phase II were similar to Phase I, with the exception of coagulants. In Phase II, lime and ferric chloride replaced the alum and polymers used during the first fifteen months of plant operation. This was done to compare the performance and costs associated with these widely used water treatment chemicals. Estimated full-scale plant costs for both processes are addressed in Chapter 11 of this report. The flocculation and sedimentation



**TOTAL BLENDED INFLUENT FLOW  
(PHASE IIA)  
FIGURE 8. 1-2**



**PERCENT ESTUARY FLOW  
IN EEWTP BLENDED INFLUENT  
(PHASE IIA)  
FIGURE 8. 1-3**

## Process Overview

processes were operated as they were in the alum mode and, therefore, are not described here.

Slaked quicklime, the primary coagulant, was added in slurry form to rapid mix tank number one throughout the entire Phase II operating period. The slurry feed was manually adjusted every hour so that a target pH was maintained through the flocculation process. Initially, the operating pH target was 11.0. This criterion was selected based on jar test results which indicated that coagulation at this pH, coupled with small amounts (2-4 mg/L) of ferric chloride used as a coagulant aid, produced optimum results with respect to turbidity and TOC removal. However, full-scale operating experience showed that acceptable settled water quality could be achieved by operating at a slightly lower pH and a ferric chloride dose of 2.0 mg/L. For the majority of Phase II the coagulation pH target was maintained at  $10.8 \pm 0.2$ . Higher ( $11.3 \pm 0.2$ ) and lower ( $10.2 \pm 0.2$ ) pH ranges were investigated in November and early December to assess the impact on water quality, sludge production and chemical requirements.

The lime dose averaged approximately 80 mg/L-CaO over the Phase II operating period. The approximate lime doses required to achieve the various operating pHs were as follows:

pH	Approximate Lime Requirement mg/L - CaO
10.0 to 10.4	50 - 60
10.6 to 11.0	75 - 85
11.0 to 11.4	125 - 135

Lime doses were calculated using the daily average slurry feed rates from hourly measurements, and the CaO content of the slurry as determined each morning by a temperature corrected density measurement of a grab sample from the lime slurry holding tank. Lime slurry concentrations were typically in the four to six percent (CaO by weight) range.

The original lime slaking and feed system was drastically modified after the start-up of the lime coagulation phase. The original make-up system was configured to operate in an automatic batch mode using low and high level sensors in a relatively small (approximately 300 gal) lime slurry holding tank to start and stop the paste slaker and produce lime slurry. The slurry was then fed to the process with a dual head, diaphragm metering pump.

However, due to several mechanical, electrical and process control problems, automatic slaking was not possible, and because of the relatively small volume of the lime slurry holding tank, operations personnel were required to manually prepare several batches of slaked lime each day. The lime slurry feed rate being pumped to the process was very erratic, causing considerable difficulty in controlling the coagulation pH. This resulted in unstable operation for the first two weeks of Phase II operation.

## Process Overview

To overcome these difficulties, a new slurry holding and feed system was installed. The 5,000 gallon sludge storage and recarbonation tank, which was not in use at the time, was converted to a lime slurry holding tank and a 1.5 inch lime slurry recirculating loop, driven by a progressive cavity sludge pump, was fabricated. Lime feed to the rapid mix was then controlled with a pinch valve on a 0.5 in line which was teed from the recycle loop near the rapid mix tanks. The new system functioned well and by early August the coagulation process was stabilized.

Ferric chloride was chosen as a coagulant aid based on results of preliminary jar testing. The ferric chloride was fed to rapid mix tank number one with a small chemical metering pump. The dose was maintained at 2.0 mg/L over the course of Phase II operations with the exception of two one week periods in early and mid-November 1982, when the low lime process was being tested. The ferric system operated without interruptions throughout Phase II of operation.

### RECARBONATION

Recarbonation refers to the process of passing carbon dioxide ( $\text{CO}_2$ ) gas through a high pH water to reduce the pH. Recarbonation of the high pH sedimentation basin effluent was accomplished in a single stage process using commercial liquid carbon dioxide.

The system consisted of a 330 ft<sup>3</sup> contacting compartment where the gaseous  $\text{CO}_2$  was introduced to the lime clarified effluent in a countercurrent flow pattern, followed by a 770 ft<sup>3</sup> holding compartment where the recarbonation reactions could be substantially completed prior to gravity filtration. The detention time in each compartment was seven and sixteen minutes, respectively.

The commercial carbon dioxide supply was contained as a liquid in a refrigerated 65,000 lb capacity, high pressure storage tank located adjacent to the EEWTP. The carbon dioxide was reduced in pressure from approximately 340 psig to 15 psig by an in-line pressure reducing valve, and introduced into the process with coarse bubble diffusers.

The recarbonation process was controlled manually based on hourly pH readings. Operations personnel measured the recarbonation effluent pH and adjusted the  $\text{CO}_2$  feed rate to achieve the desired pH.  $\text{CO}_2$  feed rates were measured and recorded every two hours to enable calculation of the instantaneous or daily average applied  $\text{CO}_2$  dose.

The post recarbonation pH target was set at 7.5 initially and then raised to the upper sevens in late November in an effort to maintain a pH of 7.5 in the finished water. (Typically, a 0.2 to 0.3 pH drop across the GAC process was observed.) Automatic operation was also attempted, but oversized flow control hardware made control difficult and the idea was abandoned.

Average applied doses were calculated from the  $\text{CO}_2$  flow records discussed above. Generally, 300 mg/L of  $\text{CO}_2$  were required to reduce the sedimentation



## Process Overview

effluent pH to the mid sevens when operating under the high lime mode (pH 11.0 to 11.3), and approximately 200 mg/L of CO<sub>2</sub> was necessary when operating in the high 10 pH range. Overall, the system operated without interruption except for planned maintenance and periods when automatic control was attempted.

### GRAVITY FILTRATION

After recarbonation, process water flowed to the gravity filtration process. The two identical filter units were described in Chapter 7. The operational procedures (rate control, backwash criteria, and procedures, etc.) used in Phase II were similar to Phase I except that all the process flow was routed through one filter from 8 January 1983 to the end of the project. This was equivalent to a unit flow rate of 6 gpm/ft<sup>2</sup>.

The gravity filters and appurtenant equipment performed reliably throughout the entire operational period. However, measurement of the anthracite bed at the end of operation indicated that an approximate ten percent media loss had occurred during Phase II operation. The losses can probably be attributed to washout by localized surges of backwash flow or by air in the backwash water.

### GRANULAR ACTIVATED CARBON ADSORPTION

Significant changes were made in the granular activated carbon (GAC) process in Phase II. These changes included:

1. Replacing the ICI Hydrodarco 8 x 16 mesh lignite based carbon with 12 x 40 mesh bituminous based Calgon F-400.
2. Doubling the empty bed contact time (EBCT) to thirty minutes by halving the flow to the GAC process. This also resulted in halving the GAC surface loading rate to approximately 4.5 gpm/ft<sup>2</sup>. Reducing the GAC feed flow by fifty percent required the installation of a bypass line from the GAC feed pump discharge to the finished water outfall. Enough water was continuously wasted from the line to maintain 0.25 MGD through the GAC process.

All other physical dimensions, features and operating criteria, with the exception of backwashing rates, were similar to Phase I and can be found in Chapter 7 of this report. Due to the smaller GAC mesh size, the carbon column backwashing rates used for Phase II were approximately forty percent lower than Phase I for a similar thirty percent bed expansion.

### FINAL DISINFECTION

Process water was pumped from the GAC clearwell to the ozone contact tank where the primary disinfectant for Phase II, ozone, was introduced. Following ozonation, ammonia and then chlorine were injected into the flow stream to form chloramines, the residual disinfectant. Each process is described in greater detail below.

## Process Overview

### Ozonation

The ozone generator used for intermediate oxidation in Phase I was also used for final disinfection in Phase II. The generator, which originally was capable of producing up to 80 lbs of ozone per day from air, was modified to reduce its output capacity considerably. Chapter 7, Section 1 details the procedures used to reduce the ozone generation capacity and also provides a description of the system.

The two stage ozone contact tank was designed for a maximum flow of 1 MGD with four passes per stage. Samples for ozone residual and bacteriological assays were taken from the tank effluent until 23 November 1982, when the sample site was moved to the last pass of the first stage. Samples from this site had approximately twenty minutes residence time within the contact tank. The second stage tank was not used for ozonation, but did provide an additional twenty minute contact time.

The ozonated air, which ranged from 0.1 to 0.4 percent ozone by weight, was diffused into passes one and three of the vertically baffled, two stage, steel contact tank. As in the intermediate ozone process, two-thirds of the ozonated air was introduced, counter-currently, into pass one and the remainder into pass three. Air to liquid ratios of approximately 0.30 and 0.15, respectively, were used in the feed passes. Off-gas from the contactor was passed through an afterburner to thermally destruct the ozone before discharge to the atmosphere. Off-gas testing indicated that approximately fifty percent ozone absorption was achieved during operation.

The applied ozone dose varied from slightly over 3 mg/L after start-up to 0.5 mg/L in late December when problems in the generator were discovered. A time series plot of ozone dose is shown in Figure 8.4-14. An analysis of final disinfection including information on ozone residual, mass balance results and disinfection efficiencies is presented in Section 4 of this Chapter under Process Analysis - Disinfection.

Two major problems developed before and during operation of the final ozonation system. The first was a problem with ozone escaping from the top of the contact tank. Because the tank proved difficult to seal completely, a blower was mounted on the contact tank off-gas vent pipe on the roof of the plant. The blower pulled a slight vacuum on the tank causing a negative pressure which prevented ozone from escaping from the tank.

The other major problem involved the apparent loss of ozone generating capacity in December 1982 and January 1983. After several weeks of noticeable loss in ozone production, the unit was taken off-line and the covers to the generator were removed. An inspection revealed that the teflon disc plugs (installed in the spaces where dielectric tubes had been removed to reduce the capacity of the unit) had rotated, thus allowing large quantities of unozonated air to pass through the generator and on to the contact tank. The net result

## Process Overview

was a lower ozone output due to dilution of the ozonated gas stream. This problem was resolved and the unit was restarted in late January 1983 and functioned properly until the end of the project.

### Chloramination

Under the proper conditions, chlorine and ammonia will react in a series of complex reactions to form chlorinated ammonia compounds. These compounds, called chloramines, are persistent and inactivate most microbiological organisms if given sufficient contact time. These characteristics made chloramines the residual disinfectant of choice in Phase II operation. Each major component of the chloramination process is discussed below.

Ammonia. A 7.5 percent ammonia solution was fed directly into the line transporting the process flow to the chlorine contact tank. A dose of 1.5 mg/L-N was selected to maintain a chlorine to ammonia mass ratio of two or three to one by weight. The total chlorine residual target was 3.0 mg/L, which required a chlorine dose of 4 to 5 mg/L. After some minor start-up difficulties with the ammonia feed system, including a change in the application point from before to after the ozone process, the system was stabilized and operated continuously.

Chlorine. Chlorine solution was added to the process flow downstream of the ammonia addition point. The chlorine was added in the vertical section of pipe which fed the chlorine contact tank. Although this was not ideal from a mixing standpoint, reasonably good mixing did occur because total and free chlorine residuals, as measured by the continuous auto analyzer and manually, were very consistent and stable. The total chlorine residual averaged 3.0 mg/L and free chlorine residual averaged less than 0.2 mg/L for the entire Phase II period.

## SECTION 2

### OVERALL PLANT PERFORMANCE

This section presents an overview of plant performance with respect to the water quality parameters monitored during Phase II of operation. It is intended to describe the overall performance of the EEWTP in terms of the change in the levels of key parameters between the influent and the finished water. The key parameters examined in this section are grouped as follows: Physical/Aesthetic, Trace Metals, Major Cations, Anions and Nutrients, Radiological, Microbiological, and Organics. Each parameter grouping generally consists of a tabular summary of each constituent measured in the influent and finished water during Phase II. The tabular summaries present the number of samples analyzed, N; the number of samples above the method detection limit, No. Detected, which were used in the calculation of statistics; the percentage of overall removal through the plant using geometric means for comparison; and the 95 percent confidence interval around the removal percentage.

#### PHYSICAL/AESTHETIC PARAMETERS

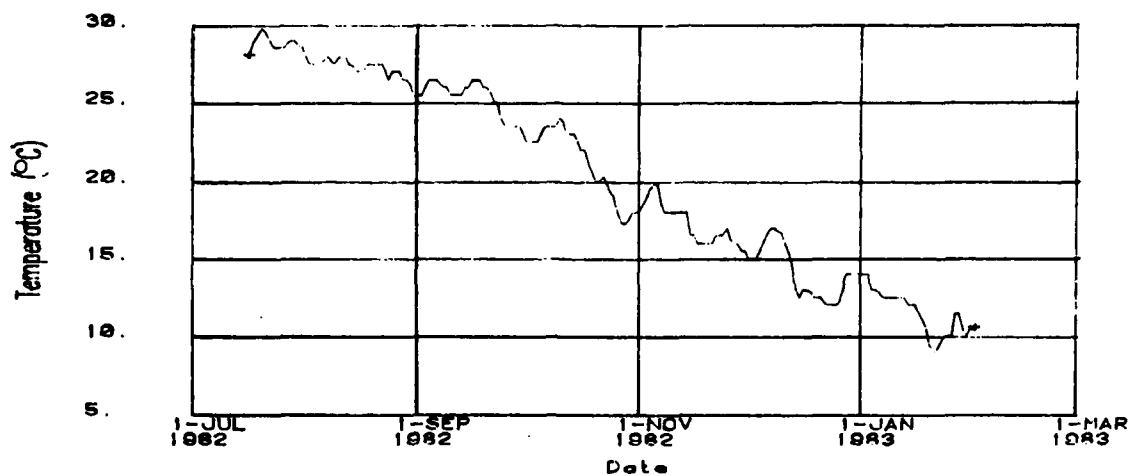
The physical/aesthetic group consists of a variety of parameters which are often used to describe the physical characteristics and potability of water. This group includes apparent color, free and total chlorine residual, methylene blue active substances (MBAS), odor, pH, corrosivity, temperature, total suspended solids (TSS), turbidity, and asbestos.

Tables 8.2-1 presents the results of all physical/aesthetic analyses performed during Phase II. Figures 8.2-1(a), (b) and (c) are time series plots of finished water temperature, influent and finished water pH and finished water free and total chlorine residual.

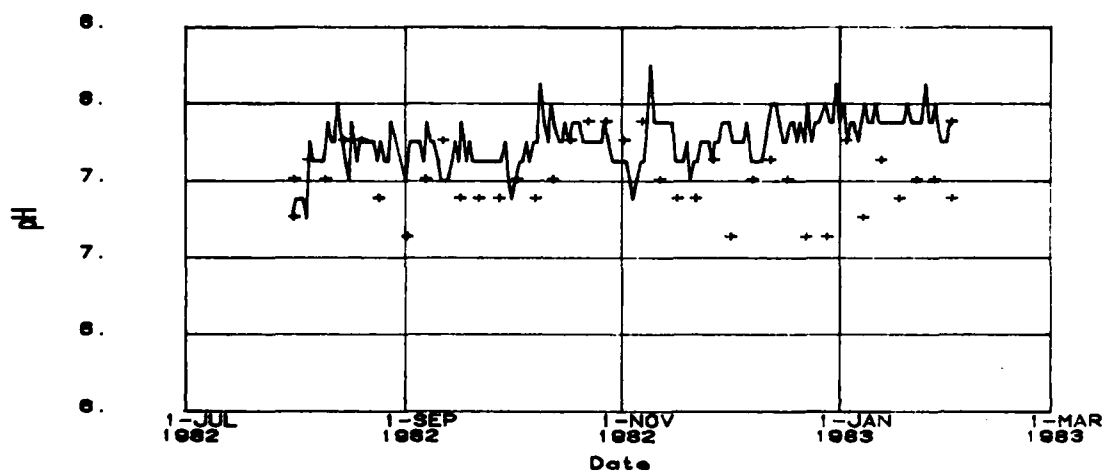
Asbestos data are presented separately in Table 8.2-2. As shown in Table 8.2-2 a decrease in chrysotile fiber concentration of over 99 percent occurred between the blend tank effluent and the finished water. Amphibole fibers were not detected at either site during this operational phase.

#### MAJOR CATIONS, ANIONS AND NUTRIENTS

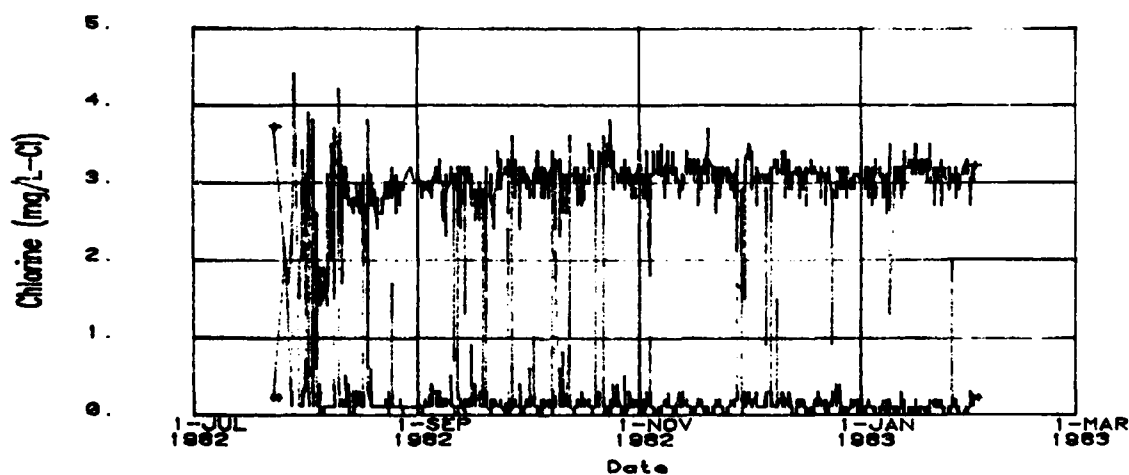
This group includes the parameters listed in Table 8.2-3. Although most of these general minerals are of little concern and their removal was not purposefully sought, the overall removal percentages with confidence intervals are given in Table 8.2-3 to provide data concerning the fate of these parameters. The change in concentration of several parameters reflects the use of chemicals in the treatment process. Ammonia and calcium are examples of this.



(a) Finished Water Temperature



(b) Blended Influent and Finished Water pH



(c) Finished Water Free and Total Chlorine Residue

## PHYSICAL/AESTHETIC PARAMETERS

(PHASE IIA)

FIGURE 8. 2-1

# Overall Plant Performance

TABLE 8-2-1  
OVERALL PROCESS PERFORMANCE  
PHYSICAL/AESTHETIC PARAMETERS  
PHASE II

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected	Geometric Mean		Lower	Upper
Apparent Color MDL=3 color units	22	22	47.3	21	21	10.5	77.8	72.8	81.9
MBAS MDL=0.03 mg/l	6	6	0.075	6	3	0.018	76.0	51.7	88.1
Turbidity MDL=0.05 NTU	1080	1080	8.72	1079	1076	0.06	99.3	99.3	99.3

<sup>1</sup> N = Number of Samples Analyzed

## Overall Plant Performance

TABLE 8.2-2

### ASBESTOS CONCENTRATIONS - PHASE IIA

<u>Concentration, MFL<sup>1</sup></u>	<u>Blended Influent</u>		<u>Finished Water</u>	
	<u>Chrysotile</u>	<u>Amphibole</u>	<u>Chrysotile</u>	<u>Amphibole</u>
Arithmetic Average	2.907	ND <sup>2</sup>	0.011	ND
Median	1.283	NC <sup>3</sup>	NC	NC
90 Percentile	7.426	NC	NC	ND

1 MFL = Million Fibers Per Liter.

2. ND = Not Detected

3. NC = Not Calculated

Section 3, Fate of Contaminants, will examine in more detail the concentration increases or decreases of a number of the parameters which were of particular interest.

### TRACE METALS PARAMETERS

This section provides data assessing the overall removal of metals from the influent water during Phase IIA. As with all Section 2 parameters, removal percentages were calculated by comparing the finished water concentration with the blended influent concentration. Confidence intervals at the 95 percent confidence level were also calculated. The trace metals data are presented in Table 8.2-4.

The removal of primary and secondary regulated trace metals is of particular importance. Of the seven primary metals, silver, cadmium, and mercury concentrations in the finished water were too low to detect and, therefore, removals could not be calculated. The concentrations of these metals were well below regulated levels. Removal percentages for arsenic, chromium and lead were 36, 70, and 94 percent, respectively. These concentrations were also below their respective maximum contaminant levels. The selenium concentration increased through the plant, although its concentration was orders of magnitude less than the maximum contaminant level for this metal. For the four secondary regulated metals, copper, iron, manganese and zinc, the percent removals were, respectively, 88, >99, >99 and 46. All finished water trace metal concentrations were below the maximum contaminant level.

## Overall Plant Performance

TABLE 8.2-3  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE II

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected	Geometric Mean		Lower	Upper
Alkalinity, as CaCO <sub>3</sub> MDL=2.7 mg/L	52	52	71.7	53	53	96.09	-34.0	-47.3	-21.9
Bromide MDL=0.003 mg/L	52	51	0.0312	53	49	0.0224	28.2	-6.1	51.4
Calcium MDL=0.2 mg/L	55	55	51.07	55	55	68.67	-34.5	-44.	-25.2
Chloride MDL=0.1 mg/L	52	52	56.05	53	53	60.78	-8.4	-13.7	-3.4
Cyanide, Total MDL=0.005 mg/L	54	18	0.0037	53	8	0.0021	43.2	-16.0	72.2
Electroconductivity MDL=0.1 umho/cm	945	945	502.4	53	53	577.7	-15.0	-18.4	-11.7
Fluoride MDL=0.10 mg/L	52	52	0.52	53	53	0.47	9.6	2.7	16.1
Hardness as CaCO <sub>3</sub> MDL=1.0 mg/L	55	55	164.8	55	55	193.7	-17.5	-24.4	-11.1
Magnesium MDL=0.1 mg/L	55	55	9.01	55	55	4.26	52.7	43.9	60.1
Nitrogen, Ammonia MDL=0.02 mg/L-N	52	49	0.177	53	48	0.491	-177.4	-331.6	-78.3
Nitrogen, Nitrite+Nitrate MDL=0.02 mg/L-N	52	52	7.72	53	53	7.71	0.1	-9.0	8.5
Nitrogen, TKN MDL=0.2 mg/L-N	52	52	1.05	53	52	0.89	15.2	-4.8	31.5
Orthophosphate MDL=0.01 mg/L-P	52	51	0.230	53	9	0.001	99.6	97.4	99.9



# Overall Plant Performance

TABLE 8.2-3 (Continued)  
OVERALL PROCESS PERFORMANCE  
MAJOR CATIONS, ANIONS AND NUTRIENTS  
PHASE II

Parameter	Blended Influent			Finished Water		Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected		Lower	Upper
Potassium MDL=0.3 mg/L	55	55	6.26	55	55	0.8	-3.4	4.9
Silica MDL=0.2 mg/L	52	52	5.47	53	53	12.2	3.6	20.1
Sodium MDL=0.1 mg/L	55	55	30.77	55	55	-2.6	-8.6	3.0
Sulfate MDL=0.6 mg/L	52	52	53.69	53	53	-1.7	-9.4	5.4
Total Dissolved Solids MDL=1 mg/L	52	52	263.8	53	53	-14.3	-19.7	-9.1

1. N = Number of Samples Analyzed.

## Overall Plant Performance

TABLE 8.2-4  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE II

Parameter	Blended Influent			Finished Water		Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected		Lower	Upper
Aluminum MDL=0.003 mg/L	55	55	0.2173	55	45	94.1	91.0	96.1
Arsenic MDL=0.0002 mg/L	55	48	0.00058	55	48	36.2	16.8	51.1
Barium MDL=0.002 mg/L	55	55	0.0303	55	55	45.2	38.7	51.1
Boron MDL=0.0040 mg/L	55	55	0.0519	55	54	25.4	13.6	35.6
Cadmium (furnace AAS) MDL=0.0002 mg/L	55	4	NC <sup>2</sup>	55	2	NC	NC	NC
Chromium (furnace AAS) MDL=0.0002 mg/L	54	52	0.0407	55	53	69.8	56.9	78.8
Copper (flame AAS) MDL=0.0012 mg/L	55	54	0.00707	55	22	86.4	79.2	91.1
Iron MDL=0.003 mg/L	55	55	0.7903	55	38	99.1	98.5	99.5
Lead MDL=0.0003 mg/L	55	53	0.0021	54	13	94.3	87.8	97.3
Lithium (Flame AA) MDL=0.0004 mg/L	54	54	0.00611	55	55	8.2	-0.9	16.5
Manganese MDL=0.0010 mg/L	55	55	0.11041	55	17	99.6	99.1	99.9
Mercury MDL=0.00027 mg/L	55	6	NC	55	10	NC	NC	NC
Nickel MDL=0.0010 mg/L	55	49	0.00406	55	30	70.2	56.3	79.7

# Overall Plant Performance

TABLE 8.2-4 (Continued)  
OVERALL PROCESS PERFORMANCE  
TRACE METALS  
PHASE II

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected	Geometric Mean		Lower	Upper
Selenium MDL=0.0002 mg/L	55	31	0.00028	55	39	0.00046	-64.3	-195.3	8.6
Silver MDL=0.0002 mg/L	55	29	0.0002	55	2	NC <sup>2</sup>			
Titanium MDL=0.0020 mg/L	55	51	0.00962	55	2	NC	>793	NC	NC
Vanadium MDL=0.0020 mg/L	55	51	0.00459	55	38	0.00266	42.0	29.0	52.7
Zinc MDL=0.0012 mg/L	55	55	0.01540	55	55	0.0083	46.1	33.4	56.5

1. N = Number of samples analyzed.

2. NC = Not calculated.

3. Overall removal calculated using the MDL as the effluent concentration.

## Overall Plant Performance

TABLE 8.2-5  
OVERALL PROCESS PERFORMANCE  
RADIOLOGICAL  
PHASE II

Parameter	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	N	Number Detected	Geometric Mean		Lower	Upper
Gross Alpha MDL=0.1 pCi/L	12	1	NC <sup>2</sup>	12	0	NC	NC	NC	NC
Gross Beta MDL=0.1 pCi/L	12	12	6.25	12	12	5.27	15.7	16.8	39.1
Strontium-90 MDL=0.2 pCi/L	7	5	0.42	1	1	0.90	-114.3	-475.1	20.2

1. N = Number of samples analyzed.

2. NC = Not calculated.

## Overall Plant Performance

### RADIOLOGICAL PARAMETERS

Table 8.2-5 contains the results of radiological analyses performed during Phase II. Gross alpha, gross beta and strontium-90 were measured. The gross alpha concentration in both the blended influent and the finished water was too low to be detected and a geometric mean was not calculated. The finished water concentration was well below the 15 pCi/L standard.

### MICROBIOLOGICAL PARAMETERS

The following parameters were measured in the EEWTP blended influent and finished water during Phase IIA: total coliforms, fecal coliforms, SPC, enteric viruses, Salmonella, and parasites. Total coliforms, fecal coliforms and SPC were measured weekly in the blend and daily (five samples/week) in the finished water. Salmonella and parasites were analyzed monthly at both locations. Enteric viruses were concentrated from large volume samples approximately once each week at both locations.

Removal of bacteria during Phase IIA was very similar to removal during Phases IA and IB except that total coliform removal was superior in Phase IIA. Table 8.2-6 shows the coliform data for Phase IIA and illustrates that the median and 90 percent values for the finished water were below the detection limit of 0.02/100 ml. The processes utilized in each operations phase removed at least 6.0 logs of total coliforms.

Decreases in fecal coliform and the SPC levels were nearly identical in each of the three phases. During Phase IIA, the fecal coliform levels were below the MDL, making a calculation of the geometric mean impossible. Ninety percent of the finished water samples analyzed for fecal coliforms had less than 0.02 coliforms per 100 ml. This was a reduction of nearly 100 percent from the blended influent value. The standard plate count also decreased by nearly 100 percent within the plant.

Seven grab samples each from the blended influent and the finished water were analyzed for the presence of Salmonella bacteria. The results of these analyses are in Table 8.2-7. Salmonella was detected in three of the seven blended influent grab samples but was not detected in any of the finished water samples.

Table 8.2-8 shows that viruses were recovered from fifty-six percent of the EEWTP blended influent samples. Blended influent concentrations ranged from 0.006 to 0.240 MPNCU/gal., as shown in Table 8.2-9. Approximately 26,000 gal of finished water from thirty samples were filtered and then concentrated prior to cell monolayer inoculation. The actual inoculations represented approximately 13,000 gallons of initial filtered samples. No viruses were detected in any of the thirty samples using both BGM and MA104 cell lines. Viruses identified from positive blended influent samples are shown in Table 8.2-10.

## Overall Plant Performance

During Phase IIA, seven blended influent samples and seven finished water samples were analyzed for parasites. The parasites which the analyses tested for were *Giardia*, *Entamoeba histolytica*, *Acanthamoeba*, *Naegleria gruberi*, *Ascaris*, Hookworm and *Trichuris trichiura*. The results of the blended influent sample analyses are presented in Table 8.2-11. All results for the finished water were negative and are presented in Table 8.2-12.

Twelve EEWTP blended influent samples were analyzed during the two years of plant operations. Parasites were detected in only one, a Phase IIA sample collected on 30 December 1982. One *Giardia* cyst and one *Entamoeba histolytica* were identified. In addition, ten nitrified effluent and twelve Potomac estuary samples were analyzed during the project. Parasites were not detected in these source waters. There were no positive identifications in the seven Phase IIA finished water samples.

# Overall Plant Performance

TABLE 8.2-6

## OVERALL PROCESS PERFORMANCE COLIFORM AND STANDARD PLATE COUNT PHASE IIA

	<u>Blended Influent</u>	<u>Finished Water</u>	<u>% Removal</u>	<u>Log- Reduction</u>
<b>Total Coliforms (MPN/100 ml)</b>				
N <sup>1</sup>	36	119		
Number Detected	36	11		
Geometric Mean	28,990	NC <sup>2</sup>	NC	NC
Median	24,000	<0.02	>99.99992	>6.1
90% Value	160,000	<0.02	>99.99999	>6.9
<b>Fecal Coliforms (MPN/100 ml)</b>				
N	31	114		
Number Detected	31	1		
Geometric Mean	7,085	NC	NC	NC
Median	7,000	<0.02	>99.99971	>5.5
90% Value	24,000	<0.02	>99.99992	>6.1
<b>Standard Plate Count (colonies/ml)</b>				
N	34	112		
Number Detected	34	29		
Geometric Mean	13,548	0.4	99.99705	4.5
Median	15,000	<1.0	>99.99333	>4.2
90% Value	28,500	2.0	>99.99298	4.2

<sup>1</sup> N = Number of Samples Analyzed.

<sup>2</sup> NC = Not Calculated

# Overall Plant Performance

TABLE 8.2-7

## OVERALL PROCESS PERFORMANCE SALMONELLA PHASE IIA

<u>Salmonella</u> <u>(MPN/100 ml)</u>	<u>Blended</u> <u>Influent</u>	<u>Finished</u> <u>Water</u>	<u>%</u> <u>Removal</u>	<u>Log-</u> <u>Reduction</u>
N <sup>1</sup>	7	7		
Number Detected	3	0		
Geometric Mean	0.19	NC <sup>2</sup>	NC	NC
Median	<0.22	<0.02	NC	NC
90% Value	0.51	<0.02	>96.1	>1.4

1. N = Number of Samples Analyzed
2. NC = Not Calculated

TABLE 8.2-8

## OVERALL PROCESS PERFORMANCE ENTERIC VIRUSES PHASE IIA

	<u>EEWTP</u> <u>Blended</u> <u>Influent</u>	<u>EEWTP</u> <u>Finished</u> <u>Water</u>
No. of Samples	32	30
Total Volume Concentrated (gallons)	7,508	26,114
Equivalent Volume Applied to Cells (gallons) <sup>1</sup>	3,754	13,057
No. of Positive Samples <sup>2</sup>	18	0

- 1 Approximately one-half of the concentrated extract was applied to the cell monolayers.
- 2 A sample was positive if it illicited cytopathic effects on at least one of the cell lines tested.



# Overall Plant Performance

TABLE 8.2-9

## ENTERIC VIRUSES EEWTP BLENDED INFLUENT PHASE IIA

<u>Sampling Date</u>	<u>Volume Filtered (Gallons)</u>	<u>Cell Line</u>	<u>Lower Detection Limit (MPNCU/Gallon)<sup>1</sup></u>	<u>Concentration (MPNCU/Gallon)</u>
Jul 22, 1982	22.0	BGM	.010	ND <sup>2</sup>
		MA104	.010	ND
Jul 29, 1982	52.0	BGM	.054	ND
		MA104	.054	ND
Aug 4, 1982	181.0	BGM	.013	ND
		MA104	.013	ND
Aug 12, 1982	147.0	BGM	.022	ND
		MA104	.022	.022
Aug 20, 1982	301.0	BGM	.011	ND
		MA104	.008	ND
Aug 25, 1982	131.0	BGM	.018	ND
		MA104	.018	ND
Sep 2, 1982	67.0	BGM	.036	ND
		MA104	.036	ND
Sep 3, 1982	106.0	BGM	.002	ND
		MA104	.002	ND
Sep 17, 1982	191.0	BGM	.013	ND
		MA104	.013	ND
Sep 24, 1982	87.0	BGM	.028	ND
		MA104	.028	ND
Oct 1, 1982	105.0	BGM	.024	ND
		MA104	.024	ND
Oct 8, 1982	105.0	BGM	.026	.054
		MA104	.019	.019
Oct 15, 1982	168.0	BGM	.015	ND
		MA104	.015	ND
Oct 22, 1982	160.0	BGM	.015	ND
		MA104	.015	ND
Oct 29, 1982	140.0	BGM	.019	.019
		MA104	.019	.019
Nov 5, 1982	570.0	BGM	.005	.005
		MA104	.005	.016
Nov 19, 1982	187.5	BGM	.012	.024
		MA104	.012	.024
Nov 23, 1982	350.0	BGM	.006	ND
		MA104	.006	ND
Dec 3, 1982	300.0	BGM	.007	.035
		MA104	.009	.079

# Overall Plant Performance

TABLE 8.2-9 (Continued)

## ENTERIC VIRUSES EEWTP BLENDED INFLUENT PHASE IIA

<u>Sampling Date</u>	<u>Volume Filtered (Gallons)</u>	<u>Cell Line</u>	<u>Lower Detection Limit (MPNCU/Gallon)</u>	<u>Concentration (MPNCU/Gallon)</u>
Dec 10, 1982	338.0	BGM	.007	ND
		MA104	.007	.007
Dec 17, 1982	350.0	BGM	.007	.007
		MA104	.007	.077
Dec 20, 1982	298.0	BGM	.009	.046
		MA104	.009	.049
Dec 30, 1982	280.0	BGM	.009	.019
		MA104	.009	ND
Jan 4, 1983	350.0	BGM	.007	ND
		MA104	.007	ND
Jan 5, 1982	315.0	BGM	.007	.007
		MA104	.007	ND
Jan 7, 1983	210.0	BGM	.011	.024
		MA104	.011	.024
Jan 14, 1983	280.0	BGM	.009	.019
		MA104	.009	.009
Jan 17, 1983	245.0	BGM	.010	.051
		MA104	.010	>.230
Jan 21, 1983	210.0	BGM	.011	.240
		MA104	.011	.240
Jan 24, 1983	385.0	BGM	.006	.006
		MA104	.006	.012
Jan 25, 1983	259.0	BGM	.009	.078
		MA104	.009	.030
Feb 15, 1983	420.0	BGM	.010	.231
		MA104	.010	>231

1. MPNCU/Gallon = Most probable number of cytopathogenic units per gallon.

2. ND = Not detected.

# Overall Plant Performance

TABLE 8-10

## VIRUSES IDENTIFIED EEWTP BLENDED INFLUENT PHASE IIA

	<u>Number of Isolates</u>
Coxsackie B1	2
Coxsackie B2	1
Coxsackie B4	9
Poliovirus type 1	1
Poliovirus type 2	1
Poliovirus type 3	3
Echovirus type 7	1
Echovirus type 32	1
Unidentified	16

TABLE 8.2-11

## PARASITE ISOLATIONS BLENDED INFLUENT PHASE IIA

Samples Assayed:	7
Total Volume Filtered (Gallons):	1029.5
Total Equivalent Observed Volume (Gallons):	512.3

<u>Parasite Name</u>	<u>Number Observed</u>
Giardia	1
Entamoeba histolytica	1
Acanthamoeba	ND <sup>1</sup>
Naegleria gruberi	ND
Ascaris	ND
Hookworm	ND
Trichuris trichirua	ND

<sup>1</sup> ND = Not detected

# Overall Plant Performance

TABLE 8.2-12

## PARASITE ISOLATIONS EEWTP FINISHED WATER PHASE IIA

Samples Assayed: 7  
Total Volume Filtered (Gallons): 2262.0  
Total Equivalent Volume (Gallons): 1063.5

<u>Parasite Name</u>	<u>Number Observed</u>
Giardia	ND <sup>1</sup>
Entamoeba histolytica	ND
Acanthamoeba	ND
Naegleria gruberi	ND
Ascaris	ND
Hookworm	ND
Trichuris trichirua	ND

<sup>1</sup> ND = Not detected

## Overall Plant Performance

### ORGANIC PARAMETERS

This section discusses the overall removal of organic compounds during the lime phase of EEWTP operation. Overall removal compares the geometric mean concentration of a given water quality parameter in the GAC effluent relative to the concentration in the blended influent. The influence of individual unit processes on the removal and/or formation of organic compounds is discussed in more detail in Sections 3 and 4.

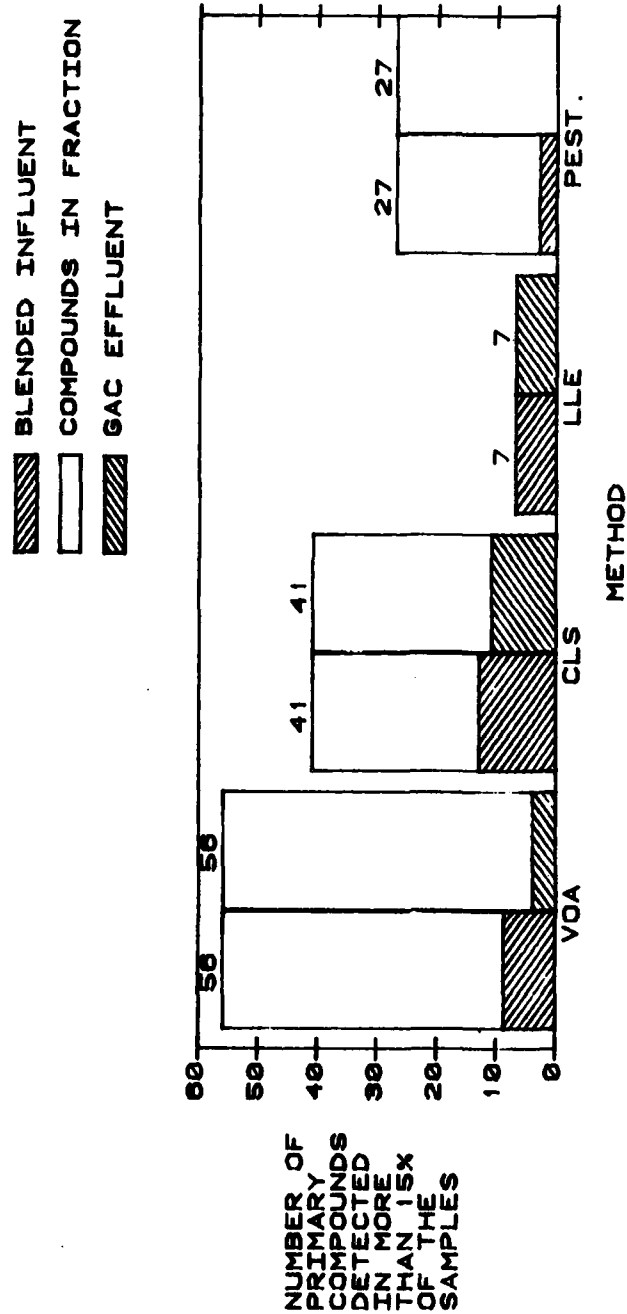
### SURROGATE PARAMETERS

The overall removals of TOC and TOX in Phase IIA are listed in Table 8.2-13. The data show that these surrogate parameters were frequently detected in both the blended influent and GAC effluent. Compared to Phases IA and IB, the overall removal of these two surrogate parameters was greatest during Phase IIA.

### PRIMARY ORGANIC COMPOUNDS

Figure 8.2-4 illustrates the overall removal of primary organic compounds detected in more than 15 percent of the samples. These primary compounds consist of a total of 151 compounds, not including the THMs. Note that primary organic compounds in the pesticide/PCB fraction were detected in the blended influent. The data show that fewer compounds in these organic fractions were detected in the GAC effluent compared to the blended influent.

As observed during Phases IA and IB, a small number of primary organic compounds were detected in either the blended influent or GAC effluent. However, figures such as these do not indicate the identity and concentration of individual compounds detected in the blended influent and GAC effluent. Table 8.2-14 lists those compounds routinely quantified in the blended influent. Fewer primary organic compounds were regularly quantified in Phase IIA compared to to Phase IA. The concentrations of all compounds listed in Table 8.2-14 in the blended influent were less than 1 µg/L. Only one of the compounds listed in this table was detected in the GAC effluent at a frequency great enough to quantify the geometric mean concentration.



OVERALL REMOVAL OF PRIMARY ORGANIC COMPOUNDS  
DETECTED IN MORE THAN FIFTEEN PERCENT OF SAMPLES  
(PHASE IIA)

FIGURE 8. 2-2

TABLE 8.2-13  
OVERALL PLANT PERFORMANCE  
REMOVAL OF SURROGATE ORGANIC PARAMETERS  
PHASE IIA

Parameter <sup>1</sup>	Blended Influent			Finished Water			Overall Removal %	95% Confidence Interval	
	N <sup>2</sup>	Number Detected	Geometric Mean	N	Number Detected	Geometric Mean		Lower	Upper
TOC (MDL=0.06 mg/L-C)	109	109	4.46	105	105	0.64	85.7	84.2	87.0
TOX (MDL=3.9 µg/L-cl)	107	107	115.83	105	89	16.07	86.1	83.3	88.5

1. Composite Samples by LLE.
2. N = Number of Samples Analyzed.

Overall Plant Performance

## Overall Plant Performance

TABLE 8.2-14  
OVERALL PLANT PERFORMANCE  
REMOVAL OF QUANTIFIED PRIMARY ORGANIC COMPOUNDS  
(EXCLUDING THMs)  
PHASE IIA

Parameter (Method, IDL)	Blended Influent		GAC Effluent		Overall Removal %	95% Confidence Interval	
	N <sup>1</sup>	Number Detected	Geometric Mean	Number Detected	Geometric Mean	Lower	Upper
1,1,1-trichloroethane (VOA, IDL=0.1 µg/L)	15	4	0.11	13	0	NC <sup>2</sup>	NC
PCE (ULE, IDL=0.1 µg/L)	108	69	0.48	107	0	NC	NC
Ethynylbenzene (CLS, IDL=0.005 µg/L)	14	4	0.01	13	3	0.0025	-78.7
1,2-dichlorobenzene (CLS, IDL=0.0001 µg/L)	14	13	0.067	13	1	NC	-99.3
1,3-dichlorobenzene (CLS, IDL=0.0001 µg/L)	14	4	0.014	13	1	NC	NC
1,4-Dichlorobenzene (CLS, IDL=0.001 µg/L)	14	11	0.031	13	1	NC	NC

1. N = Number of samples analyzed.

2. NC = Not calculated.

3. Since the geometric mean was not determined, the IDL was used to compute the overall removal.



## SECTION 3

### FATE OF CONTAMINANTS

This section explores those parameters of special interest or concern from a health, operational or aesthetic standpoint. The parameters discussed are classified according to the major groups established in Section 2.

#### PHYSICAL/AESTHETIC PARAMETERS

The physical aesthetic parameters discussed in this section include: apparent color, corrosivity, odor, and turbidity.

##### APPARENT COLOR

The distribution of apparent color at three EEWTP locations are shown in Figure 8.3-1. The sites include blended influent, filter clearwell and finished water clearwell. Although none of the finished water samples exceeded the secondary MCL of fifteen color units, fifty percent of the samples were equal to it. Overall color removal in Phase IIA was slightly inferior to Phase I. Use of intermediate oxidants in the first fifteen months may have been responsible for this.

##### CORROSIVITY

As Figure 8.3-2 shows, the Langlier Index of the finished water was maintained close to the target value of zero. This indicates a stable condition with respect to calcium carbonate saturation which is used as an empirical indicator of the corrosivity of a water. Details concerning the Langlier Index can be found in Section 3 of Chapter 7.

##### ODOR

The geometric mean value for the threshold odor number (TON) in Phase IIA was 5.2. This value was approximately one-half of the Phase IB value and one-third of Phase IA. The reduction in odor number in Phase IIA can probably be attributed to the replacement of free chlorine with ozone and chloramines in the final disinfection process.

As discussed in Chapter 7, most comments from the panel conducting the evaluation described the aroma of the finished water as chlorinous, and it was theorized that the source of the odors were compounds such as nitrogen trichloride which can result from free chlorine and ammonia reactions. The elimination of free chlorine and the use of ozone which can also oxidize odor causing compounds appears to have been a reasonably good choice of process alternatives to achieve the odor reduction.

## Fate of Contaminants

A time series plot of TON in the EEWTP finished water is presented in Figure 8.3-3. Although the odor number often exceeded the MCL of 3 TON, it should be noted that these values were below one of the local treatment plants in over ninety percent of the samples taken.

### TURBIDITY

Cumulative frequency distributions of turbidity in the plant influent, sedimentation effluent, gravity filter effluent and finished water are shown in Figure 8.3-4. The geometric means of the blended influent and finished water were 8.72 and 0.06 NTU, respectively. Approximately 75 percent of this reduction occurred in the sedimentation process. Most of the remaining turbidity was removed in the gravity filtration process, which had a geometric mean value of 0.10 NTU. Both gravity filter effluent and finished water turbidities were well below the SMCL of 1.0 NTU.

### MAJOR CATIONS, ANIONS AND NUTRIENTS

The general mineral parameters evaluated in greater detail here include: hardness, nitrate, sodium, and total dissolved solids (TDS).

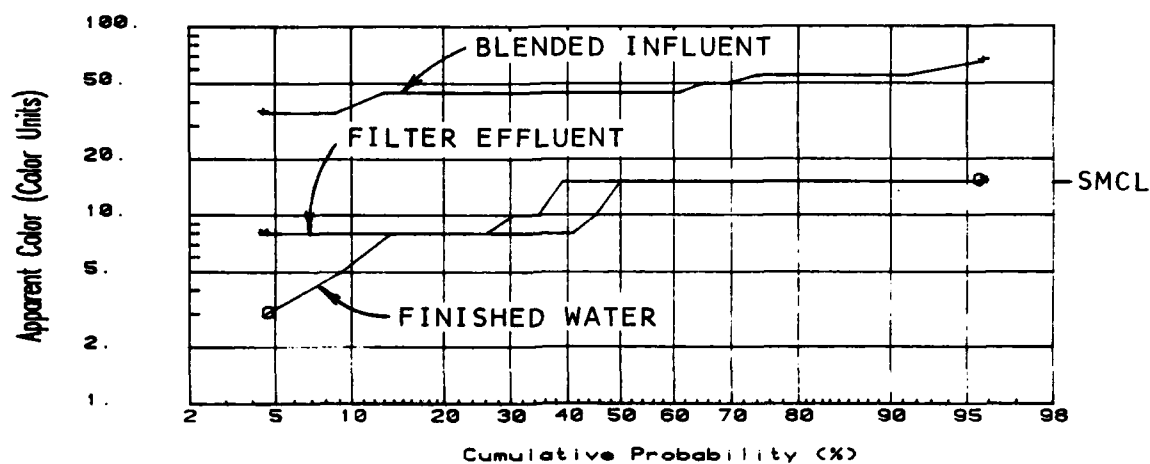
### HARDNESS

Hardness in water is caused primarily by calcium and magnesium ions and is expressed in units of equivalent concentration as calcium carbonate. There is no regulation governing hardness in water and permissible levels are usually based on consumer acceptance. Generally, a water is regarded as "soft" when hardness levels are less than 100 mg/L-CaCO<sub>3</sub>; 100 to 200 mg/L usually constitutes "moderately hard" water; and water containing more than 200 mg/L may be considered as "hard."

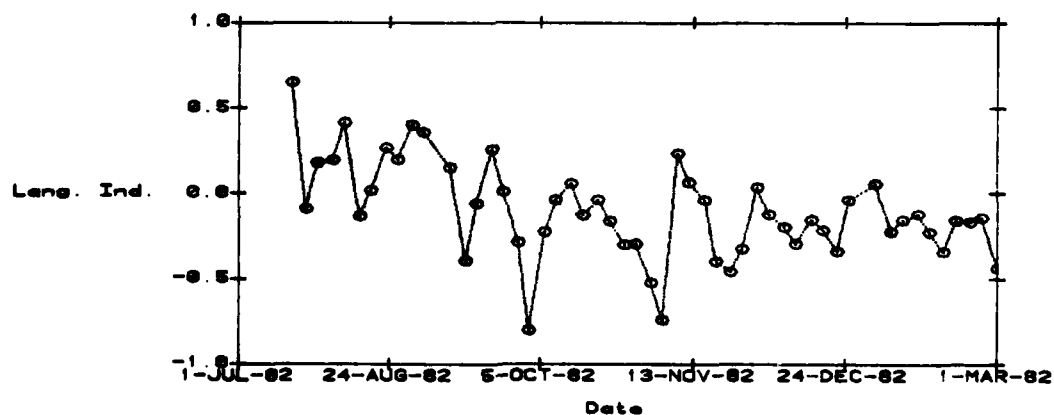
Distributions of hardness concentrations at three plant sites are presented in Figure 8.3-5. As shown in the figure, there was an increase in the hardness of the finished water when compared to the blended influent at all probability percentiles greater than five, and over thirty percent of all finished water samples exceeded 200 mg/L. This is a result of excess lime treatment. If this level of hardness were determined to be unacceptable, additional treatment for calcium removal would be required. Details concerning lime coagulation and its effect on hardness are presented in Section 4 of this chapter.

### NITRATE

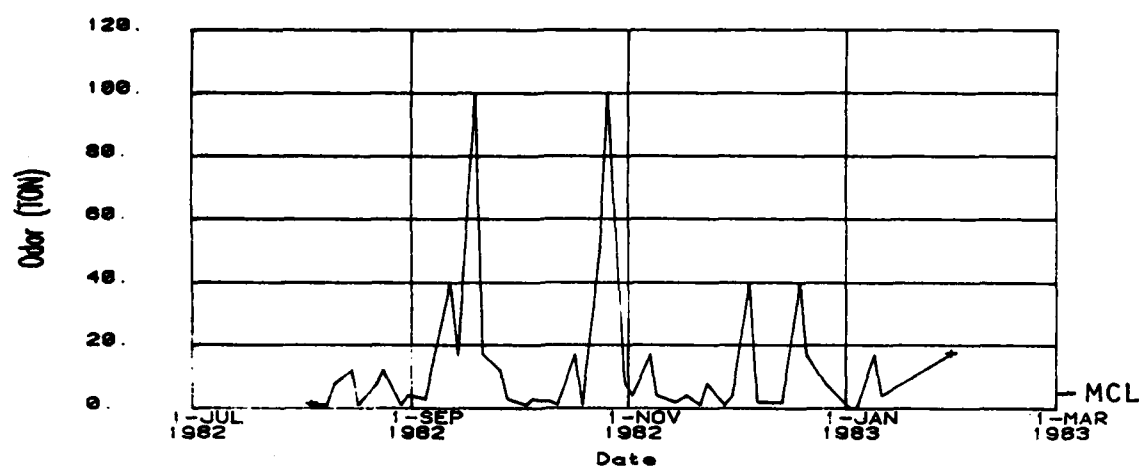
A time series plot of nitrite and nitrate concentrations in the EEWTP finished water is presented in Figure 8.3-6. As shown in the figure, nitrite and nitrate levels were frequently at or near the MCL of 10 mg/L, and exceeded this limit once. Further examination of the figure reveals two troughs in mid and late September of 1982. These coincided with the times when 100 percent estuary water was used. This highlights the fact that almost all nitrite and nitrate originated from the nitrified WWTP effluent.



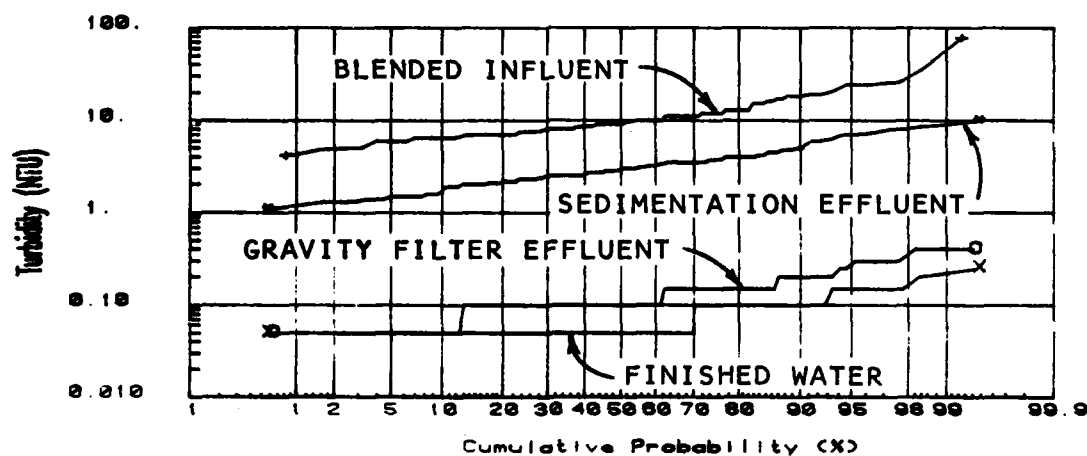
**DISTRIBUTION OF APPARENT COLOR  
(PHASE IIA)  
FIGURE 8. 3-1**



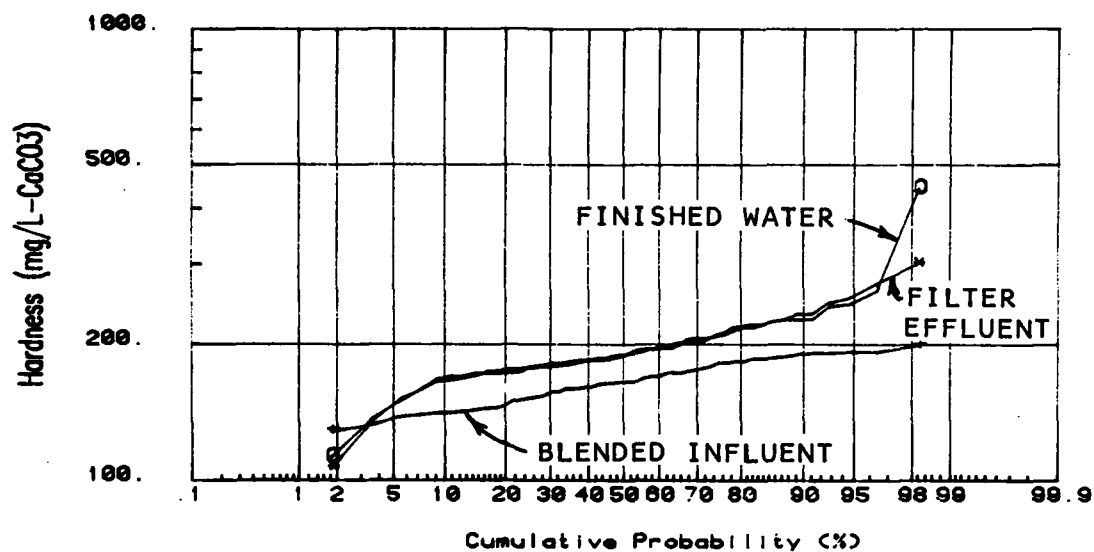
**LANGELIER INDEX OF FINISHED WATER  
(PHASE IIA)  
FIGURE 8. 3-2**



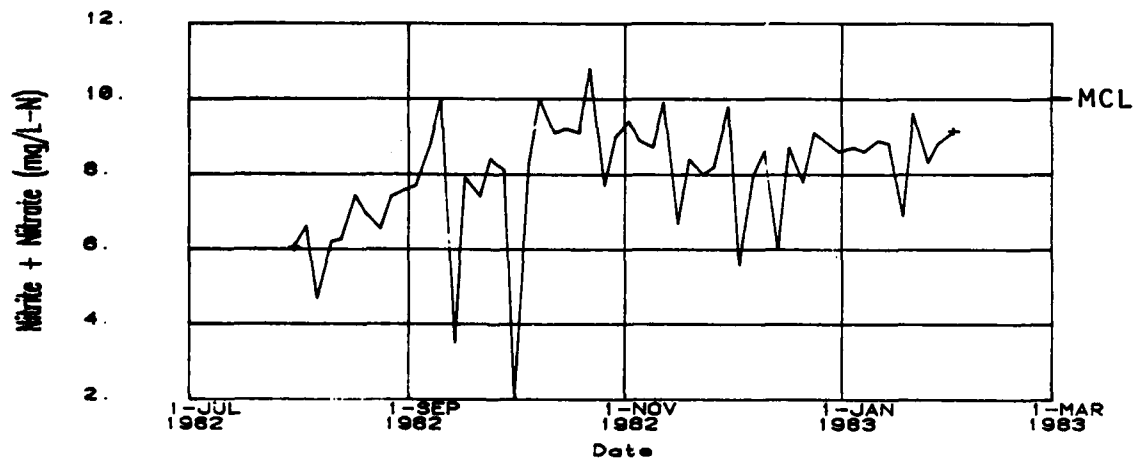
**FINISHED WATER THRESHOLD ODOR NUMBER  
(PHASE IIA)  
FIGURE 8.3-3**



**DISTRIBUTION OF TURBIDITY  
(PHASE IIA)  
FIGURE 8.3-4**



**DISTRIBUTION OF HARDNESS  
(PHASE IIA)  
FIGURE 8.3-5**



**FINISHED WATER NITRITE + NITRATE  
(PHASE IIA)  
FIGURE 8.3-6**

## Fate of Contaminants

Nitrate is unaffected by the treatment processes used at the EEWTP and unless some form of demineralization such as ion exchange or reverse osmosis is used on all or a portion of the plant flow, finished water concentration of nitrate will be equivalent to influent concentrations.

### SODIUM

As with nitrate, excessive intake has been implicated in health related problems, and because of its high solubility it is unaffected by conventional treatment. The major raw water source of sodium is nitrified secondary effluent. A suggested maximum sodium level of 20 mg/L has been proposed by the EPA.

Figure 8.3-7 is a time series plot of sodium in the EEWTP finished water during Phase IIA. The figure is similar to the time series plot of sodium shown in Chapter 7 in that concentrations increased in the colder months probably due to storm runoff containing salt. The periods at low concentration corresponded to outages on the Blue Plains source.

### TOTAL DISSOLVED SOLIDS

Figure 8.3-8 is a time series plot of total dissolved solids in the finished water. Although higher than in Phase I, concentrations were well below the 500 mg/L SMCL.

## TRACE METAL PARAMETERS

All trace metals concentrations were well within the allowable limits as specified by the primary and secondary drinking water standards established by the U.S. EPA. EEWTP finished water trace metal concentrations were also comparable to the local plants monitored and, therefore, are not an issue here. However, to demonstrate in-plant removal, short presentations of lead and manganese are provided below.

### LEAD

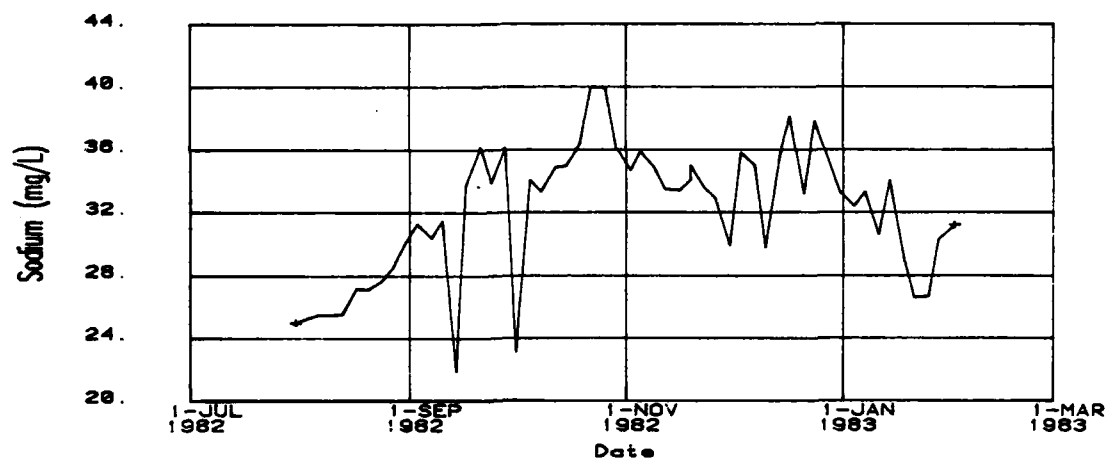
Distributions of lead at three plant sites are shown in Figure 8.3-9. The figure shows that all removal occurred in the chemical clarification and filtration processes.

### MANGANESE

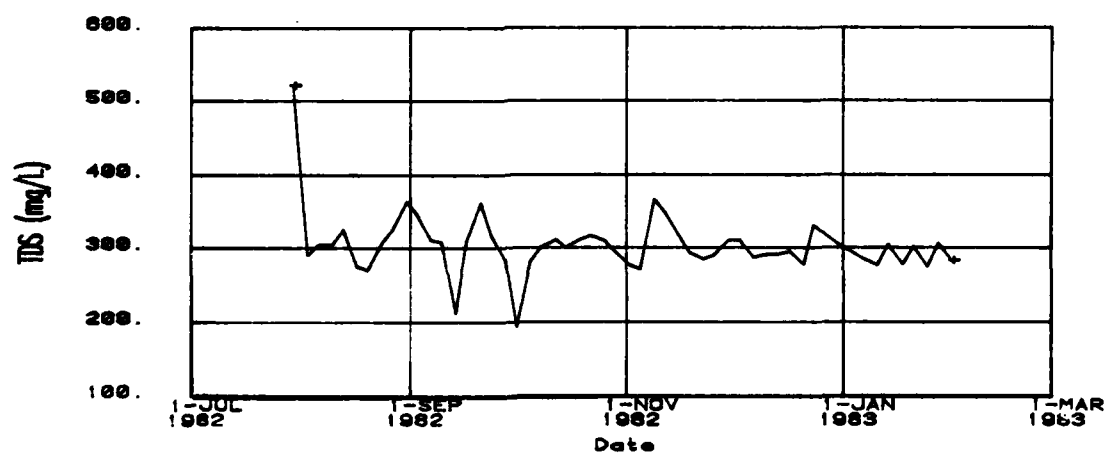
As shown in Figure 8.3-10, finished water concentrations of manganese never exceeded the SMCL of 0.05 mg/L. Removal occurred in the chemical clarification, filtration and GAC processes.

## MICROBIOLOGICAL PARAMETERS

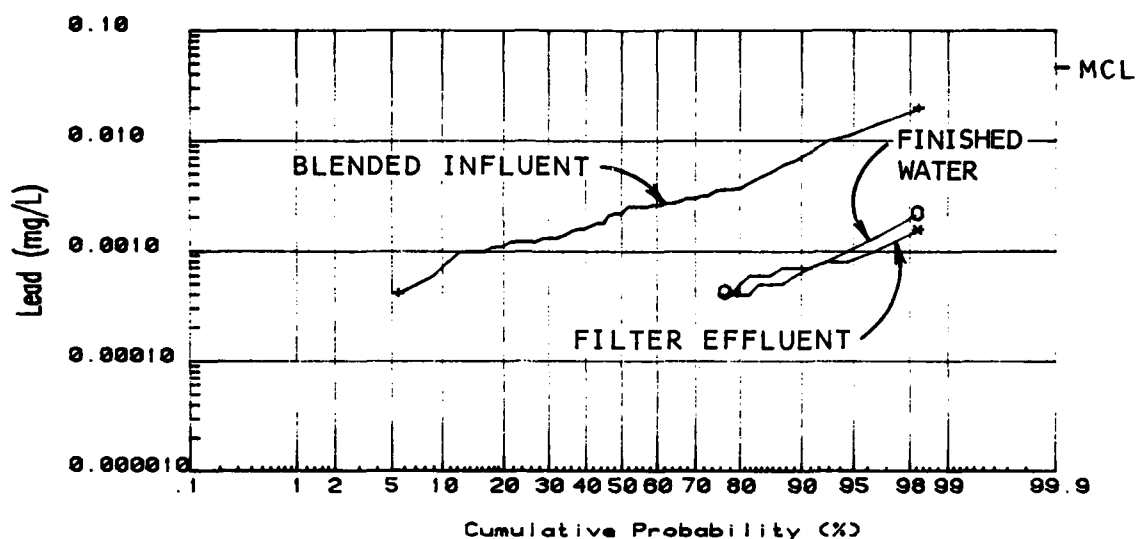
Overall performance of the EEWTP was presented in Section 2 of this chapter for all microbiological parameters monitored in the blended influent and finished water. This section discusses the fate of total coliforms and SPC



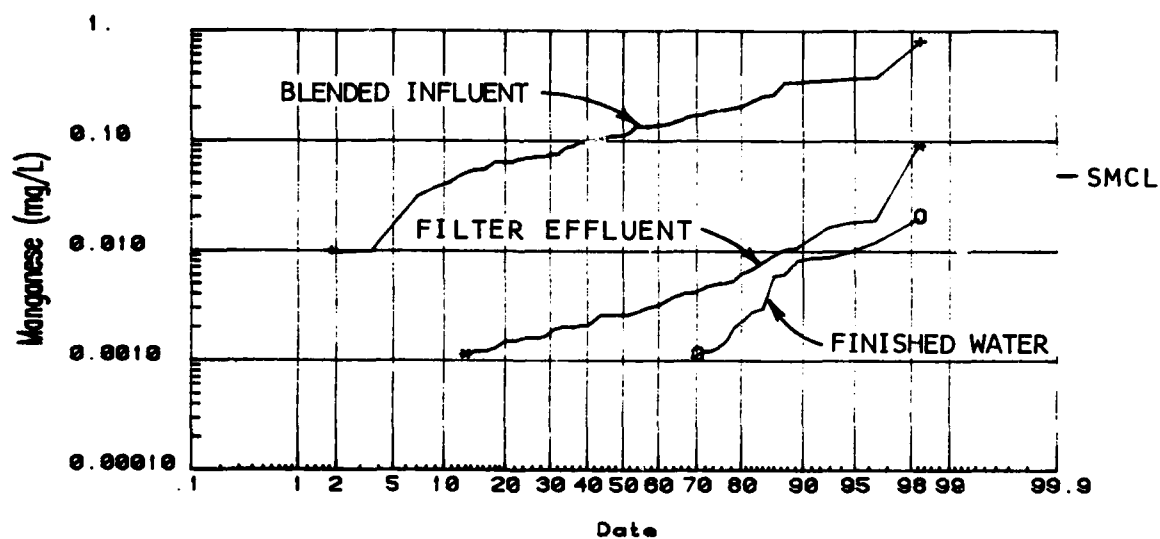
**FINISHED WATER SODIUM  
(PHASE IIA)  
FIGURE 8. 3-7**



**FINISHED WATER  
TOTAL DISSOLVED SOLIDS  
(PHASE IIA)  
FIGURE 8. 3-8**



**DISTRIBUTION OF LEAD  
(PHASE IIA)  
FIGURE 8. 3-9**



**DISTRIBUTION OF MANGANESE  
(PHASE IIA)  
FIGURE 8. 3-10**



AD-A136 864

OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
POTOMAC ESTUARY E. (U) MONTGOMERY (JAMES M) CONSULTING  
ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

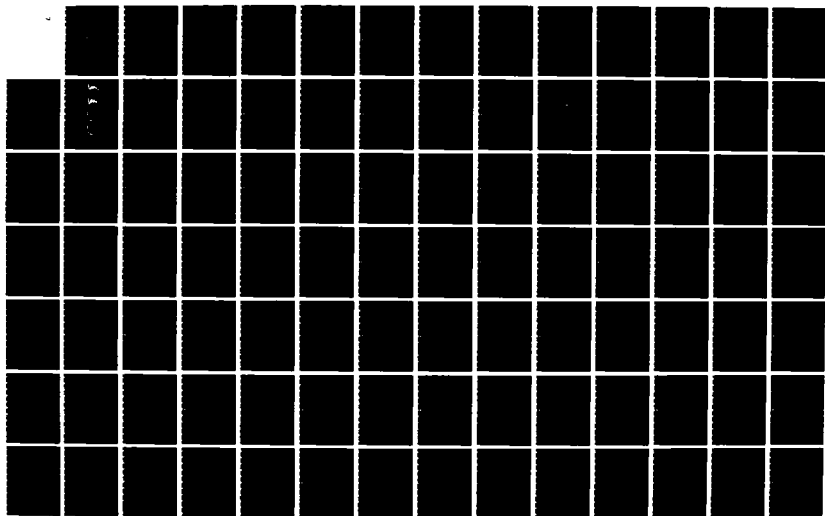
6/10

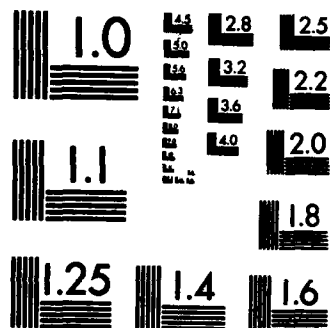
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

## Fate of Contaminants

bacteria through the Phase IIA processes. The following sites monitored during Phase IIA provided data for evaluating individual processes:

<u>Sampling Location at Influent to Process</u>	<u>Sampling Location at Effluent of Process</u>	<u>Unit Processes Evaluated</u>
1. EEWTP Blended Influent	Sedimentation Effluent	Coagulation
2. Sedimentation Effluent	Gravity Filter Effluent	Filtration
3. Gravity Filter Effluent	Final Carbon Column Effluent	GAC
4. Final Carbon Column Effluent	Ozonated Effluent	Ozonation
5. Ozonated Effluent	Finished Water	Chloramination

Table 8.3-1 summarizes Phase IIA total coliform and SPC statistical parameters. Additional sampling sites at the sedimentation tank effluent and between ozonation and residual disinfection with chloramines allowed more processes to be isolated for evaluation.

### TOTAL COLIFORMS

Total coliforms were monitored five days per week in the final carbon column effluent, ozonated effluent and finished water. EEWTP blended influent, sedimentation tank effluent, and gravity filter effluent were analyzed weekly.

### Cumulative Process Removal

Cumulative process removal of total coliforms in terms of geometric mean log removal is presented in Table 8.3-2. These data and the data in Table 8.3-3 were derived from Table 8.3-1. Coagulation and gravity filtration removed 2.7 logs of total coliforms with the majority of removal occurring during lime coagulation and sedimentation (2.2 logs). Carbon columns removed an additional 1.2 logs after filtration. Ozone was a highly effective final disinfectant, removing 3.4 logs of coliforms from the carbon column effluent. (During Phase IA and IB, two to three logs were removed using free chlorine as the final disinfectant.) Chloramination after ozonation provided additional disinfection. Overall, Phase IIA was superior to Phases IA and IB in removal of total coliform organisms.

### Individual Process Evaluation

A probability distribution plot of total coliform concentrations at each monitored site is shown in Figure 8.3-11. Individual process performance is shown in Table 8.3-3.

# Fate of Contaminants

TABLE 8.3-1  
PROCESS PERFORMANCE  
MICROBIOLOGICAL PARAMETERS  
PHASE IIA

EEWTP Blended Influent	Sedimentation Effluent	Gravity Filtration Effluent	Final Carbon Column Effluent	Ozonated Effluent	EEWTP Finished Water	Overall Log Reduction
36	28	27	122	93	119	NC <sup>1</sup>
2.9x10 <sup>4</sup>	1.9x10 <sup>2</sup>	6.3x10 <sup>1</sup>	3.8	1.3x10 <sup>-3</sup>	NC	NC
2.4x10 <sup>4</sup>	2.4x10 <sup>2</sup>	5.4x10 <sup>1</sup>	3.3	<2.0x10 <sup>-2</sup>	<2.0x10 <sup>-2</sup>	>6.1
1.6x10 <sup>5</sup>	2.4x10 <sup>3</sup>	2.4x10 <sup>2</sup>	3.5x10 <sup>1</sup>	5.0x10 <sup>-2</sup>	<2.0x10 <sup>-2</sup>	>6.9
34	26	27	116	86	112	4.5
1.4x10 <sup>4</sup>	1.0x10 <sup>3</sup>	4.9x10 <sup>2</sup>	2.7x10 <sup>1</sup>	5.0x10 <sup>-1</sup>	4.0x10 <sup>-1</sup>	>4.2
1.5x10 <sup>4</sup>	9.5x10 <sup>2</sup>	5.3x10 <sup>2</sup>	2.5x10 <sup>1</sup>	<1.0	<1.0	4.2
2.9x10 <sup>4</sup>	3.95x10 <sup>3</sup>	2.4x10 <sup>3</sup>	1.4x10 <sup>2</sup>	8.0	2.0	

Total Coliforms (MPN/100 ml)

Number of Samples  
Geometric Mean  
Median  
90% Value

Standard Plate Count (CFU/ml)

Number of Samples  
Geometric Mean  
Median  
90% Value

1. NC = Not Calculated

TABLE 8.3-2  
CUMULATIVE REMOVAL OF TOTAL COLIFORMS  
PHASE IIA

	Cumulative Geometric Mean Log Reduction				
	Lime Coagulation/ Sedimentation Effluent	Gravity Filtration Effluent	GAC Effluent	Ozonation Effluent	Finished Water
Phase IIA	2.2	2.7	3.9	7.3	>7.3

## Fate of Contaminants

TABLE 8.3-3

### REMOVAL OF TOTAL COLIFORMS BY PHASE IIA EEWTP PROCESSES

	PROCESS				
	<u>Chemical Clarifi- tion</u>	<u>Gravity Filtration</u>	<u>GAC</u>	<u>Ozonation</u>	<u>Chloram- ination</u> <sup>1</sup>
Geometric Mean Log Removal	2.2	0.5	1.2	3.5	<3.5
Geometric Mean Percent Removal	>99	67	94	>99	>99

<sup>1</sup> No geometric mean was calculated because less than 15% of samples were positive.

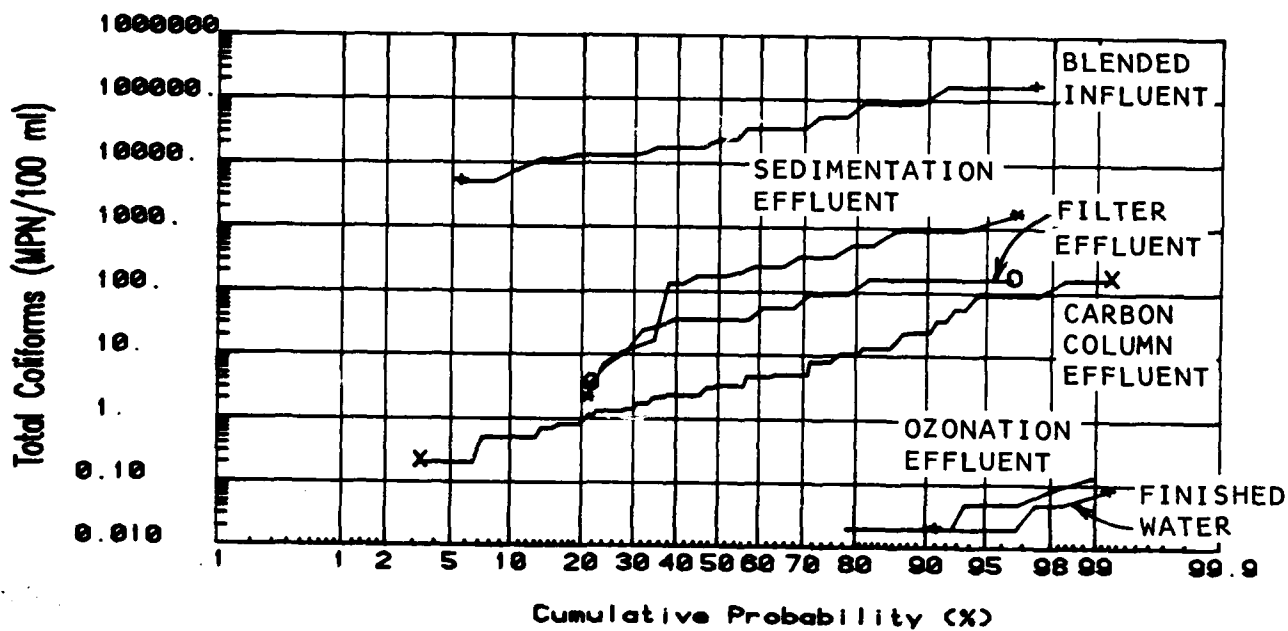
Ozone was an effective disinfectant, reducing the geometric mean value of coliforms in the GAC effluent by 3.5 logs. Final disinfection with chlorine in Phases IA and IB removed 2.0 and 3.1 logs, respectively. Ozonated effluent was treated with ammonia and chlorine producing chloramines, which could act as a residual disinfectant in a hypothetical distribution system. It was also observed that the chloramines were effective in disinfecting coliforms which broke through ozonation, especially during the last few months of operations when the applied ozone dose decreased causing an increase in coliform isolations in the ozonated effluent. A more detailed discussion of disinfection is found in Section 4 of this chapter.

#### STANDARD PLATE COUNT (SPC)

EEWTP samples were analyzed for SPC bacteria at the same locations and frequencies as total coliforms. Aliquots for SPC and coliforms were taken from the same collection bottles.

#### Cumulative Process Removal

Phase IIA EEWTP operation removed 4.5 logs of SPC from the blended influent, which had a geometric mean concentration of approximately 14,000 CFU/ml as shown in Table 8.3-4.

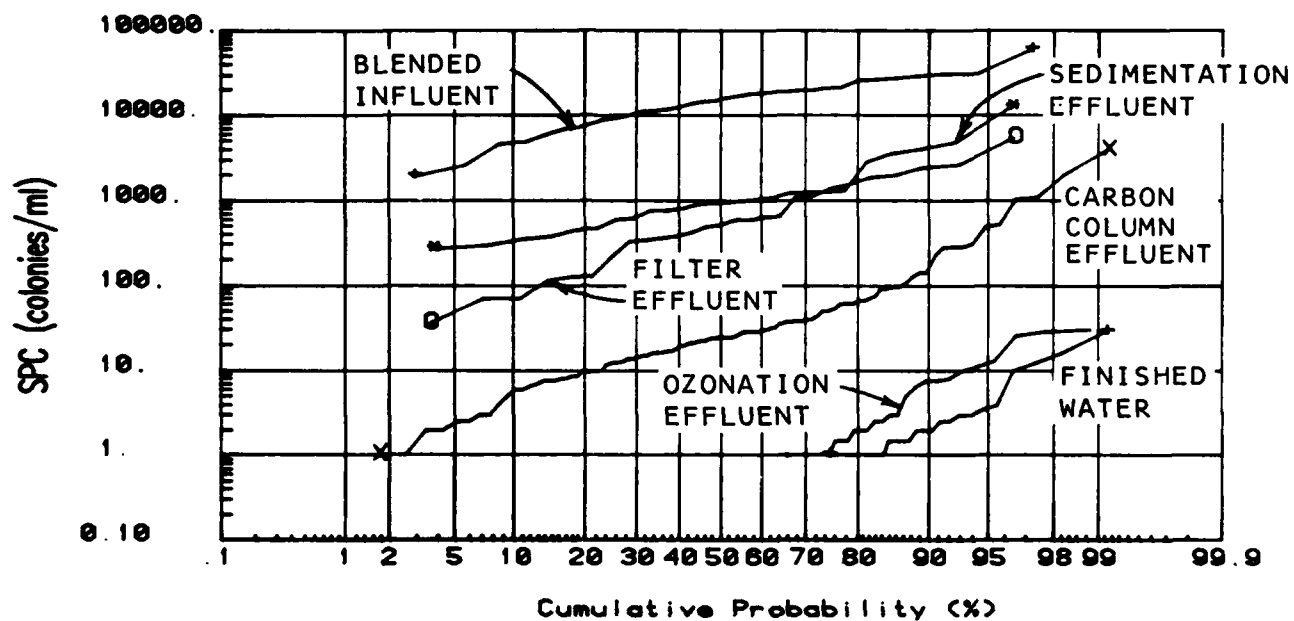


**DISTRIBUTION OF  
 TOTAL COLIFORM BACTERIA  
 (PHASE IIA)  
 FIGURE 8. 3-11**

TABLE 8.3-4  
CUMULATIVE REMOVAL OF SPC BACTERIA  
PHASE IIA

	Cumulative Geometric Mean Log Reduction				
	Lime Coagulation/ Sedimentation Effluent	Gravity Filtration Effluent	GAC Effluent	Ozonation Effluent	Finished Water
Phase IIA	1.1	1.5	2.7	4.4	4.5





DISTRIBUTION OF  
STANDARD PLATE COUNT BACTERIA  
(PHASE IIA)  
FIGURE 8. 3-12

## Fate of Contaminants

Cumulative removal after gravity filtration was 1.5 logs, most of which occurred during lime coagulation (1.1 logs). Phase IIA removal through the filtration process was equal to the removal observed during Phase IB.

### Individual Process Evaluation

A probability distribution plot of SPC concentrations at each monitored site is presented in Figure 8.3-12. Individual process performance is shown in Table 8.3-5

TABLE 8.3-5  
REMOVAL OF SPC BY PHASE IIA  
EEWTP PROCESSES

	PROCESS				
	Chemical Clarifi- tion	Gravity Filtration	GAC	Ozonation	Chloro- mination
Geometric Mean Log Removal	1.1	0.3	1.3	1.7	0.1
Geometric Mean Percent Removal	93	51	94	98	20

## ORGANIC PARAMETERS

This section discusses the effects of individual unit processes at the EEWTP on the removal and/or formation of organic compounds during Phase IIA. Plots of cumulative probability of concentrations for specific parameters are used to illustrate these effects.

### SURROGATE PARAMETERS

#### TOC

The distribution of TOC at three EEWTP sampling sites during Phase IIA are plotted in Figure 8.3-13. The geometric mean blended influent concentration during Phase IIA was comparable to the concentrations observed during Phases IA and IB. In addition to the greater observed overall removal of TOC as measured between the blended influent and GAC effluent during Phase IIA, GAC was seen to remove a greater amount of TOC compared to the other phases of EEWTP operation. This was due to the longer EBCT used during Phase IIA. The duration of this phase did not permit equivalent exhaustion of the GAC, relative to Phase IA.

### TOX

The effect of coagulation/flocculation/sedimentation on the distribution of TOX during Phase IIA is shown in Figure 8.3-14. As observed during Phases IA and IB, approximately 25 percent of the TOX in the blended influent was removed by these processes.

The effect of GAC on the distribution of TOX during Phase IIA is shown in Figure 8.3-15. As shown by comparing Figures 8.3-14 and 8.3-15, the TOX concentration was not increased by filtration. No intermediate disinfectant was used during this phase of EEWTP operation. A higher degree of TOX removal, as indicated by the geometric mean concentration, was observed during Phase IIA, than during Phase IA and IB, again due to the longer EBCT as discussed above.

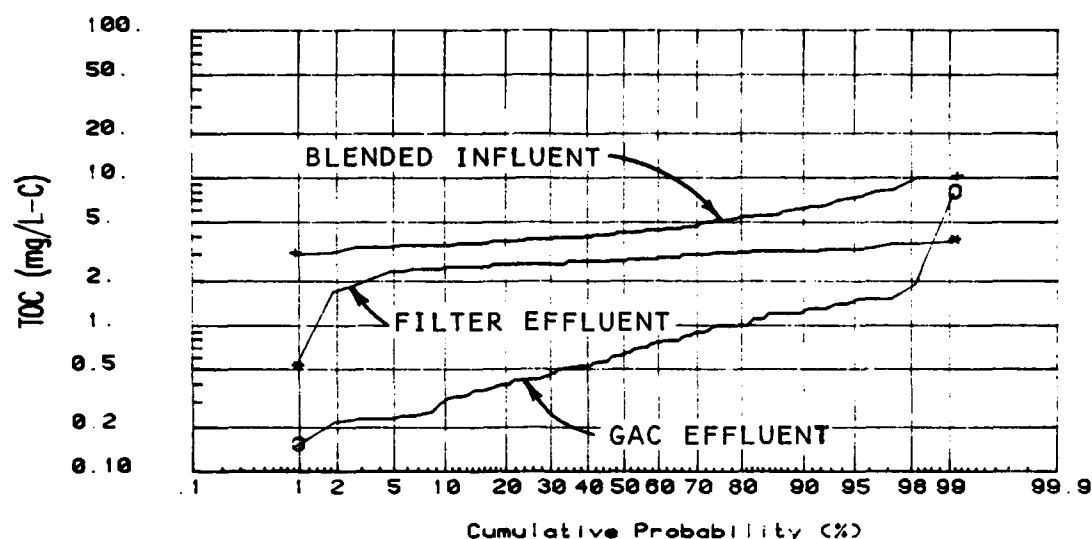
The effect of final disinfection with chloramines on the distribution of TOX is shown in Figure 8.3-16. Not only was the concentration of TOX in the GAC effluent lower during Phase IIA, but chloramines produced a smaller absolute increase in the concentration of TOX than in Phases IA and IB. Thus, the distribution of TOX concentration in the EEWTP finished water had the lowest geometric mean concentration during Phase IIA.

### PRIMARY ORGANIC COMPOUNDS

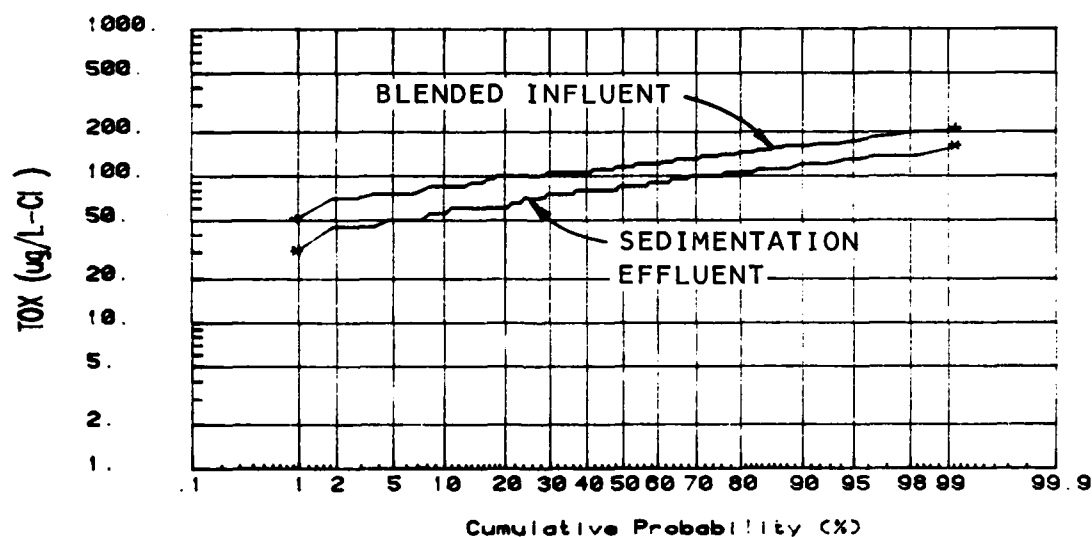
Figure 8.3-17 illustrates the fate of the organic compounds targeted for routine quantification during Phase IIA. The figure indicates the number of primary compounds detected in more than 15 percent of the samples at the four sites. The total number of routinely monitored organic compounds (i.e., primary organics) was 151. Thus, a small fraction of these compounds were detected at the four sites shown in the figure. A fewer number of these compounds were detected at each of the four sites during Phase IIA than in Phase IA or IB.

This figure does not specify the identity or concentrations of the compounds comprising the groups detected at each site. The sections below discuss these issues in more detail.

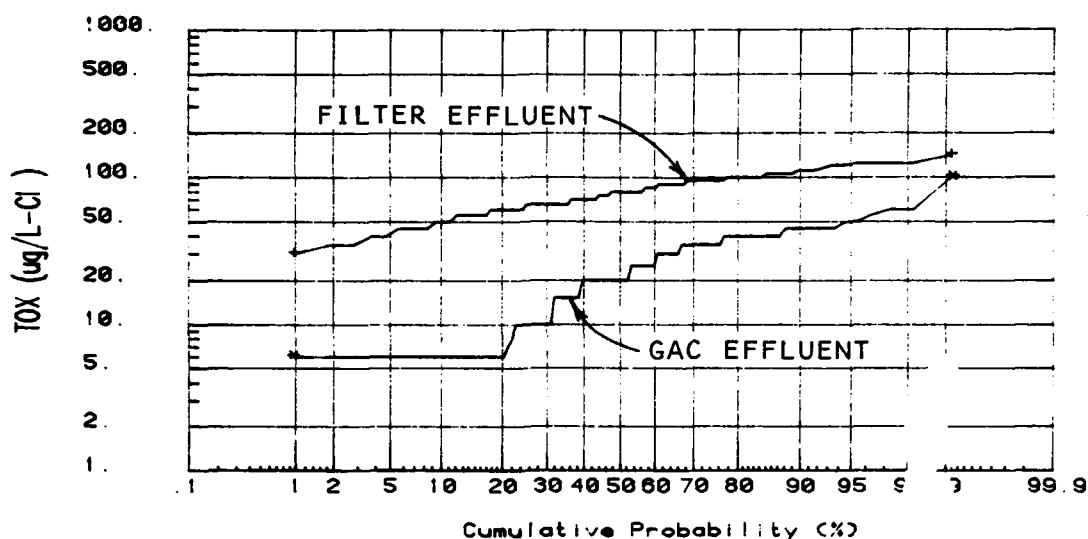
Figures 8.3-18 and 8.3-19 present chromatograms for the volatile organic fraction and pesticide/PCB fraction, respectively, at several sampling sites for one sampling date during Phase IIA. Note that Figure 8.3-19 represents samples which were analyzed in the splitless mode. While this technique increased the sensitivity, relative to samples analyzed in Phases IA and IB, the chromatograms look more cluttered. As observed for the volatile organic fraction in Phases IA and IB, Figure 8.3-18 shows that while GAC adsorption completely or partially removed some compounds found in the blended influent, final disinfection formed some new compounds. This series of chromatograms also illustrates the effectiveness of GAC adsorption in reducing the number and concentration of these more hydrophobic compounds.



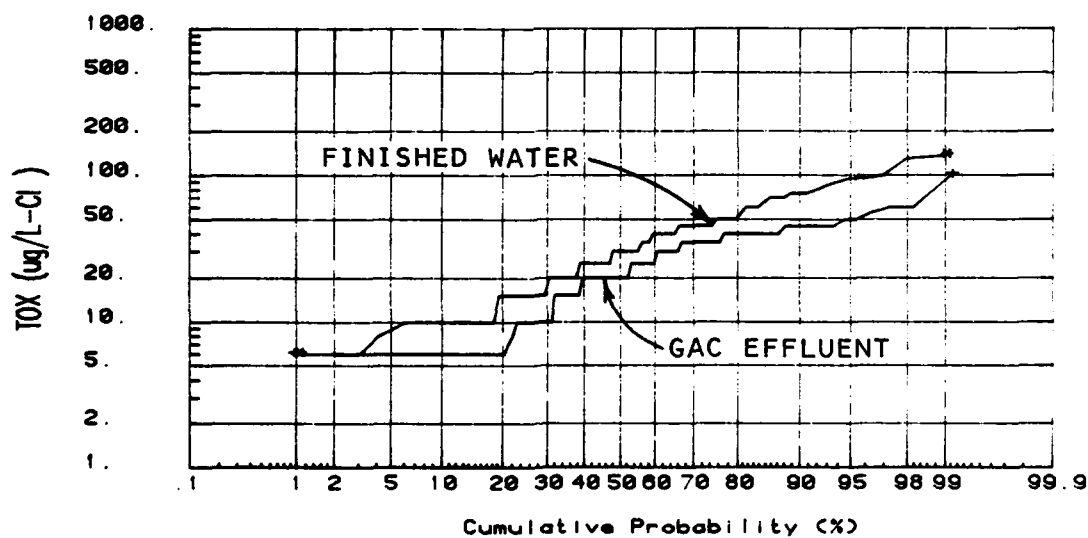
**DISTRIBUTION OF TOC  
(PHASE IIA)  
FIGURE 8. 3-13**



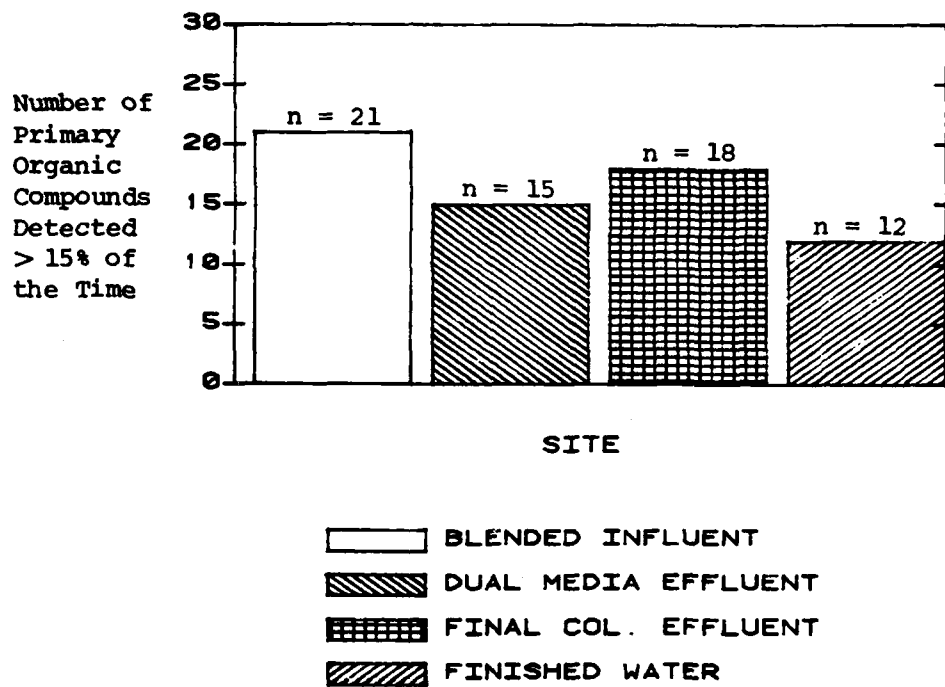
**EFFECT OF COAGULATION/SEDIMENTATION  
ON TOX DISTRIBUTION  
(PHASE IIA)  
FIGURE 8. 3-14**



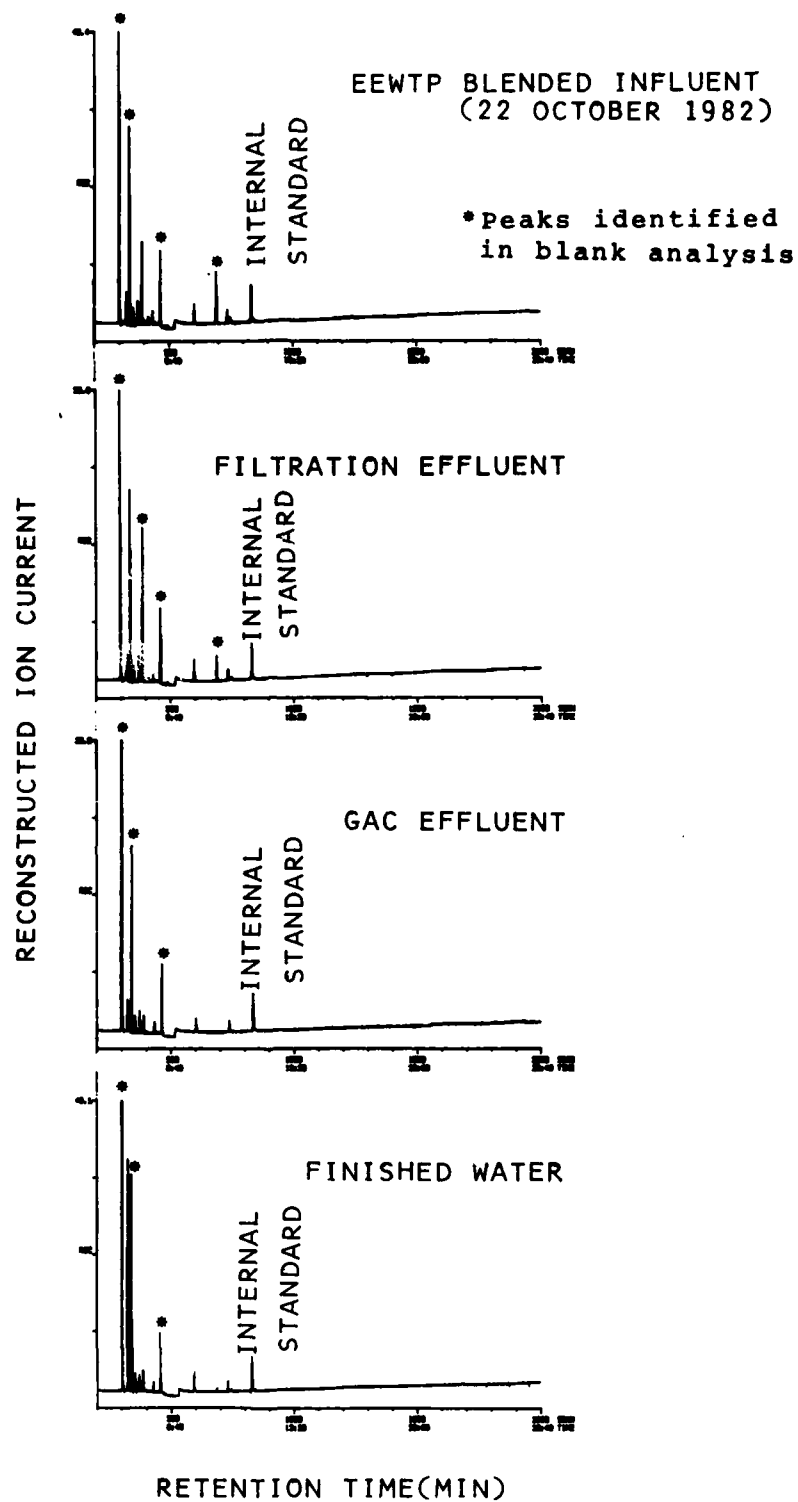
**EFFECT OF GAC ON TOX DISTRIBUTION  
(PHASE IIA)  
FIGURE 8. 3-15**



**EFFECT OF CHLORAMINATION  
ON TOX DISTRIBUTION  
(PHASE IIA)  
FIGURE 8. 3-16**

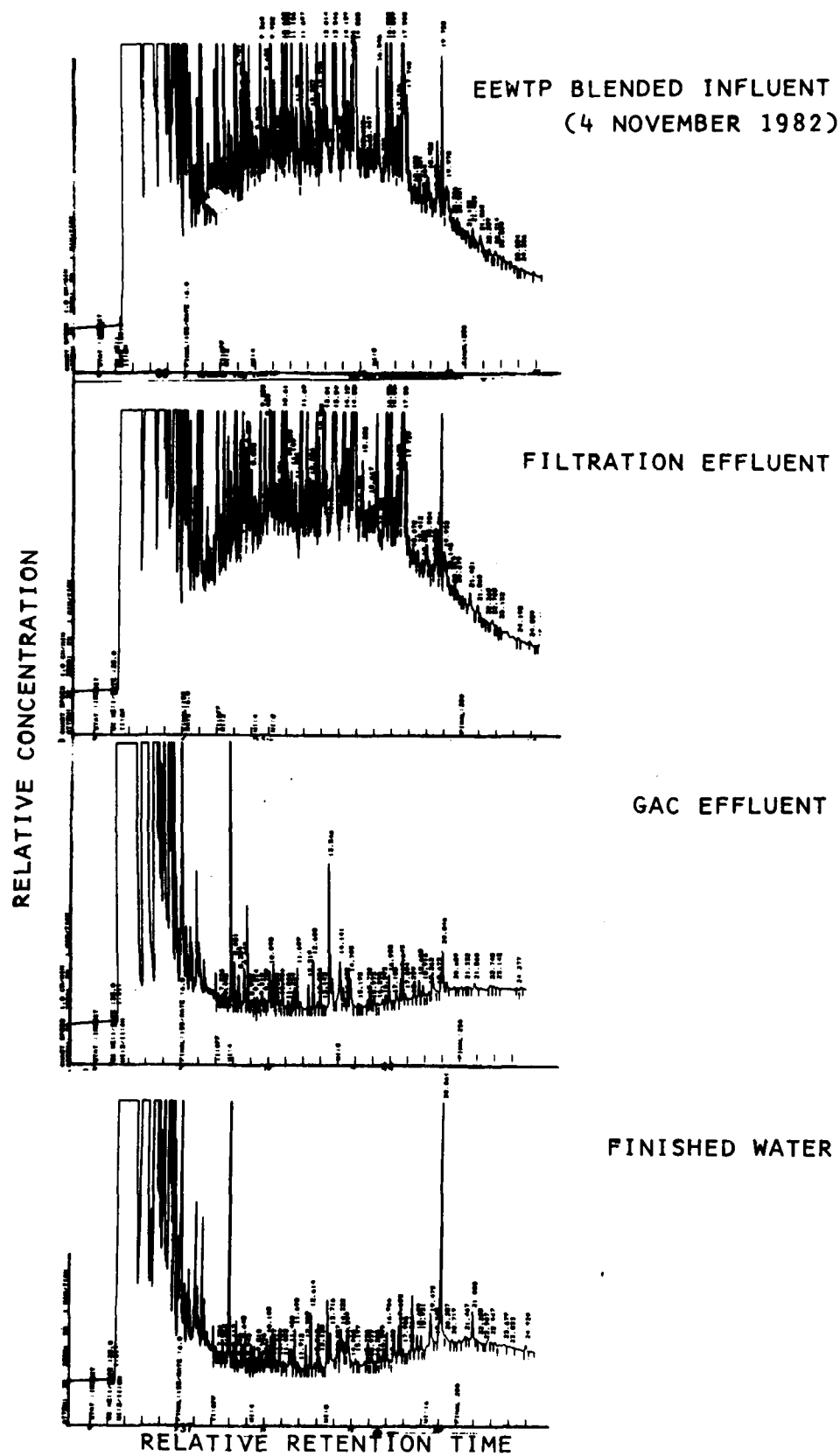


**FATE OF PRIMARY ORGANIC COMPOUNDS  
ALL FRACTIONS  
(PHASE IIA)  
FIGURE 8. 3-17**



GC/MS CHROMATOGRAMS OF  
VOLATILE ORGANIC FRACTION  
(PHASE IIA)

FIGURE 8. 3-18



GC CHROMATOGRAMS OF PESTICIDE/PCB FRACTION  
(PHASE IIA)  
FIGURE 8.3-19



## Fate of Contaminants

Table 8.3-6 lists those primary compounds detected in more than fifteen percent of samples from at least one of the EEWTP sampling sites during Phase IIA. The table also helps to point out the relative sensitivities of the analytical methods used, as several compounds were analyzed by different methods. Of the 25 different compounds detected among all sites, only chloroform had a geometric mean concentration greater than or equal to 1  $\mu\text{g/L}$ . Moreover, chloroform was detected at these levels only in the blended influent, sedimentation effluent, and filter effluent. No compounds were detected in the finished water with geometric mean concentrations greater than 1  $\mu\text{g/L}$ .

### THMs

The effect of GAC on the distribution of chloroform, the most predominant THM species, is shown in Figure 8.3-20 for Phase IIA. Compared to Phase IA, the geometric mean concentration of chloroform was less in both the filtered influent and GAC effluent. In addition, the fractional removal of chloroform by GAC was greater in Phase IIA.

### Selected SOC's

Of the 151 compounds targeted for routine quantification, a small number were found in the blended influent during Phase IIA, as was shown in Figure 8.2-4. Tetrachloroethene was chosen as an example because it was detected in a high percentage of the samples during Phase IIA, and had the highest geometric mean concentration in the blended influent. The effect of coagulation/flocculation/sedimentation/filtration on the distribution of tetrachloroethene during Phase IIA is shown in Figure 8.3-21. The data show that these unit processes reduce the geometric mean concentration of tetrachloroethene to below the MDL of 0.4  $\mu\text{g/L}$ . The geometric mean concentration in the GAC effluent could not be calculated, as less than fifteen percent of the samples had concentrations greater than the MDL.

Table 8.3-7 lists the pesticides detected at EEWTP sampling sites during the two years of operation. All quantified pesticides were detected during Phase IIA. However, no pesticides were ever detected in the EEWTP finished water, and were detected only once in the GAC effluent.

## SECONDARY ORGANIC COMPOUNDS

Figure 8.3-22 illustrates the fate of secondary organic compounds at the EEWTP during Phase IIA. The number of compounds detected at the four sites indicated are comprised of those organic compounds tentatively identified and quantified at least once. The number of secondary compounds found in the blended influent is comparable to the number found during Phase IB. During Phase IIA, compared to Phase IA and IB, the removal of secondary organic compounds by the unit processes coagulation/flocculation/sedimentation/filtration was greater during Phase IIA.

# Fate of Contaminants

TABLE 8.3-6  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN  
FIFTEEN PERCENT OF SAMPLES  
PHASE IIA

Parameter And Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Chloroform by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	106/108 1.81/1.30 1.8/2.4	104/108 2.14/1.28 2.1/3.0	105/105 2.08/1.32 2.1/2.9	87/107 0.48/3.73 0.5/2.3	96/99 0.77/2.90 0.8/2.8
Chloroform by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	15/15 1.61/1.35 1.5/2.2	NM	12/13 1.61/2.01 1.7/2.8	6/13 0.21/6.90 <0.1/2.1	8/13 0.37/5.85 0.3/3.4
Bromodichloromethane by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	108/108 0.40/1.44 0.4/0.6	106/108 0.35/1.30 0.3/0.5	105/105 0.34/1.28 0.3/0.5	29/107 NC <0.1/<0.3	96/99 0.20/2.59 <0.3/0.9
Bromodichloromethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	7/15 0.16/2.61 <0.1/0.5	NM	3/13 NC <0.1/<0.2	1/13 NC <0.1/<0.1	3/13 0.06/5.21 <0.1/0.8
Bromodichloromethane by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	14/14 0.1902/2.13 0.240/0.500	NM	9/9 0.1751/1.67 0.170/0.440	12/13 0.0274/3.82 <0.070/0.220	9/10 0.0166/15.30 <0.070/0.270
Dibromochloromethane by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	108/108 0.21/1.48 0.2/0.3	106/108 0.19/1.39 <0.1/0.3	100/105 0.18/1.35 <0.2/0.3	0/107 NC <0.1/<0.1	69/99 0.10/3.87 <0.1/0.8
Dibromochloromethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/15 NC <0.1/<0.4	NM	1/13 NC <0.1/<0.1	0/13 NC <0.1/<0.1	2/13 NC <0.1/<0.4
Dibromochloromethane by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	14/14 0.1022/3.13 0.088/0.460	NM	9/9 0.0573/3.53 0.060/0.610	9/13 NC <0.050/<0.050	10/10 0.0075/10.02 <0.050/0.091
Bromoform by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	11/108 NC <0.1/<0.2	9/108 NM <0.1/<0.1	7/105 NC <0.1/<0.1	1/107 NC <0.1/<0.1	21/99 0.04/5.03 <0.1/0.4

TABLE 9.3-6 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN  
FIFTEEN PERCENT OF SAMPLES  
PHASE IIA

Parameter And Method	Sampling Location and Concentration (µg/L)					Fate of Contaminants	
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water		
Bromoform by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	8/14 0.0071/9.00 <0.040/0.100	NM	4/9 NC <0.005/0.670	0/13 NC <0.005/<0.005	6/10 0.0019/35.72 <0.040/0.041		
Dichloromethane (methylene chloride) by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	3/15 NC <0.1/<2.0	NM	2/13 NC <0.1/<2.0	3/13 NC <0.1/<2.0	2/13 NC <0.1/<2.0		
Trichlorofluoromethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/15 NC <0.1/<0.4	NM	4/13 NC <0.1/<0.4	1/13 NC <0.1/<0.1	1/13 NC <0.1/<0.1		
1,1-Dichloroethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/15 NC <0.1/<0.6	NM	1/13 NC <0.1/<0.1	1/13 NC <0.1/<0.1	2/13 NC <0.1/<0.6		
1,1,1-Trichloroethane by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/15 0.11/2.44 <0.1/0.4	NM	4/13 0.15/1.56 <0.1/0.3	1/13 NC <0.1/<0.1	2/13 NC <0.1/<0.2		
Tetrachloroethene by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	108/108 0.48/2.18 0.5/1.3	108/108 0.30/2.28 <0.4/0.8	104/105 0.27/2.56 <0.4/1.0	43/107 NC <0.1/<0.4	4/99 NC <0.1/<0.1		
Tetrachloroethene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	15/15 0.65/2.15 0.5/1.7	NM	12/13 0.40/2.52 <0.5/1.4	0/13 NC <0.5/<0.5	0/13 NC <0.5/<0.5		
Tetrachloroethene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	13/14 0.3452/2.89 0.360/0.950	NM	7/9 0.1040/3.88 0.180/0.610	11/13 0.0404/2.63 0.044/0.110	9/10 0.0532/3.13 0.053/0.170		

TABLE 8.3-6 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN  
FIFTEEN PERCENT OF SAMPLES  
PHASE IIA

Parameter And Method	Sampling Location and Concentration (µg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
Trichloroethene by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	52/108 NC <0.1/<0.3	36/108 NC <0.1/<0.3	40/105 NC <0.1/<0.3	12/107 NC <0.1/<0.3	1/99 <0.1/<0.1
Trichloroethene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	3/15 NC <0.1/<0.7	NM	1/13 NC <0.1/<0.1	0/13 NC <0.1/<0.1	1/13 NC <0.1/<0.1
Trichloroethene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	5/14 NC <0.001/0.095	NM	1/9 NC <0.001/0.130	2/13 NC <0.001/0.070	3/10 0.1012/1.60 <0.001/0.170
Ethylbenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	6/14 0.0102/3.46 <0.005/0.043	NM	4/9 NC <0.005/0.044	9/13 0.0025/19.91 <0.020/0.100	4/10 0.0023/12.48 <0.005/0.021
Ethylbenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/14 NC <0.005/<0.040	NM	1/9 NC <0.005/<0.040	4/13 0.0161/2.48 <0.005/0.052	3/10 NC <0.005/0.052
Propylbenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/14 NC <0.001/<0.01	NM	0/9 NC <0.001/<0.001	2/13 NC <0.001/<0.01	2/10 NC <0.001/<0.01
Toluene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/14 NC <0.020/<0.090	NM	0/9 NC <0.020/<0.020	2/13 NC <0.020/<0.090	1/10 NC <0.020/<0.020
1,2-Xylene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/14 NC <0.005/<0.030	NM	2/9 NC <0.005/0.038	4/13 NC <0.005/<0.030	3/10 NC <0.005/<0.030

TABLE 6.3-6 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN  
FIFTEEN PERCENT OF SAMPLES  
PHASE IIA

Parameter And Method	Sampling Location and Concentration (μg/L)				
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water
1,3-Xylene/1,4-Xylene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/14 NC <0.005/<0.040	NM	1/9 NC <0.005/<0.040	4/13 0.0380/1.05 <0.005/0.040	3/10 NC <0.005/<0.040
1,2-Dichlorobenzene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	9/15 0.18/1.50 <0.2/0.3	NM	8/13 0.17/1.27 <0.2/0.2	0/13 NC <0.1/<0.1	0/13 NC <0.1/<0.1
1,2-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	14/14 0.0668/2.39 0.058/0.190	NM	9/9 0.0547/3.10 0.053/0.390	1/13 NC <0.0001/<0.0001	0/10 NC <0.0001/<0.0001
1,3-Dichlorobenzene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/15 NC <0.1/<0.1	NM	2/13 NC <0.1/<0.2	0/13 NC <0.1/<0.1	0/13 NC <0.1/<0.1
1,3-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	14/14 0.0142/1.99 <0.0200/0.035	NM	8/9 NC <0.0200/0.040	3/13 NC <0.0001/<0.0200	2/10 NC <0.0001/<0.0200
1,4-Dichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	14/14 0.0314/2.01 0.028/0.056	NM	9/9 0.0297/1.90 0.026/0.093	5/13 NC <0.001/<0.0200	1/10 NC <0.0001/<0.0001
1,2,4-Trichlorobenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	2/14 NC <0.001/<0.020	NM	3/9 NC <0.001/<0.020	0/13 NC <0.001/<0.001	0/10 NC <0.001/<0.001
Gamma-BHC by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	7/7 0.046/1.67 0.04/0.15	NM	6/7 0.031/2.21 0.03/0.13	0/7 NC <0.01/<0.01	0/7 NC <0.01/<0.01

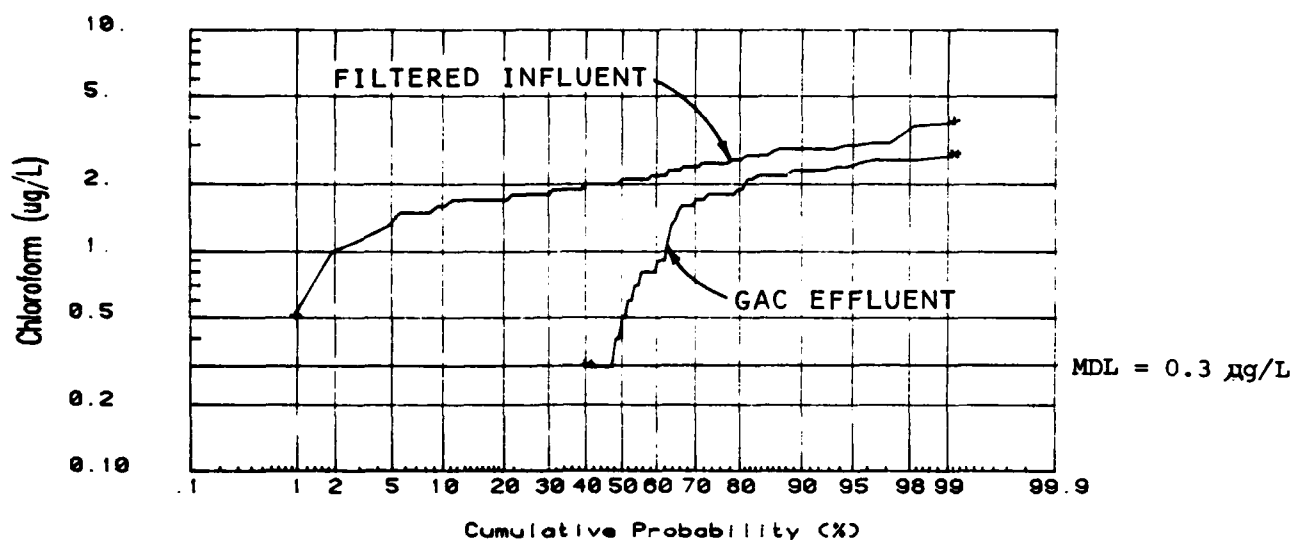
Fate of Contaminants

TABLE 8.3-6 (Continued)  
SUMMARY OF FATE OF PRIMARY ORGANIC COMPOUNDS DETECTED IN MORE THAN  
FIFTEEN PERCENT OF SAMPLES  
PHASE IIA

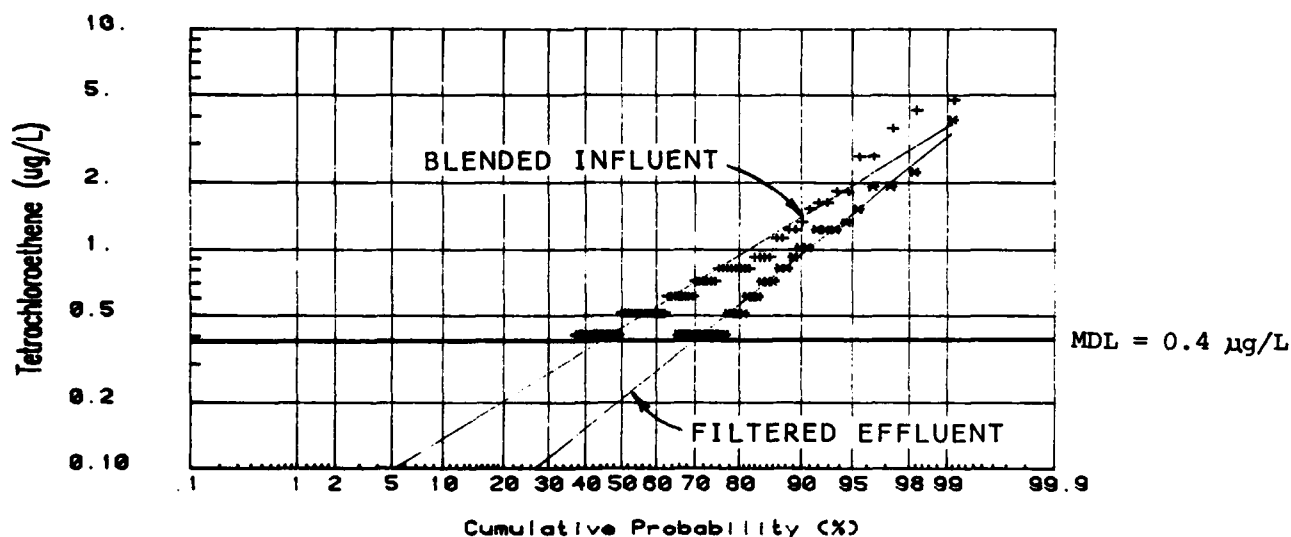
Parameter And Method	Sampling Location and Concentration (µg/L)					Fate of Contaminants	
	Blended Influent	Sedimentation Effluent	Filter Effluent	GAC Effluent	Finished Water		
Endosulfan I by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	4/7 NC <0.01/<0.03	NM	2/7 NC <0.01/<0.03	0/7 NC <0.01/<0.01	0/7 NC <0.01/<0.01		
2,4,D by LLE (w/methylation) Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/6 NC <0.1/0.2	NM	0/7 NC <0.1/<0.1	1/7 NC <0.1/0.2	0/7 NC <0.1/<0.1		
Tetrahydrofuran by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	5/15 0.08/10.27 <0.1/1.7	NM	3/13 0.07/4.83 <0.1/0.5	2/13 0.06/3.03 <0.1/0.2	1/13 NC <0.1/<0.1		
Acetone by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	1/15 NC <0.5/<0.5	NM	1/13 NC <0.5/<0.5	0/13 NC <0.5/<0.5	4/13 0.09/41.26 <0.5/7.3		
Geosmin by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	3/14 NC <0.0005/<0.05	NM	3/9 NC <0.0005/<0.05	1/13 NC <0.0005/<0.0005	2/10 NC <0.0005/<0.0005		

a. Not measured at this sampling site.

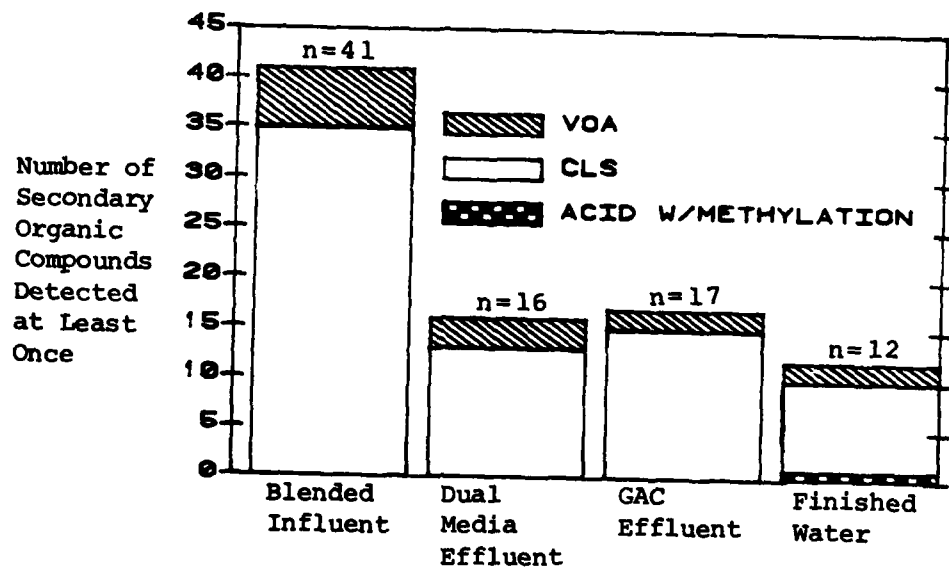
b. Not calculated (i.e., less than 15 percent of samples were  $\geq$  MDL).



**EFFECT OF GAC ON  
CHLOROFORM DISTRIBUTION  
(PHASE IIA)  
FIGURE 8. 3-20**



**EFFECT OF GAC ON  
TETRACHLOROETHENE DISTRIBUTION  
(PHASE IIA)  
FIGURE 8. 3-21**



**FATE OF SECONDARY ORGANIC COMPOUNDS  
(PHASE IIA)**

**FIGURE 8. 3-22**



# Fate of Contaminants

TABLE 8.3-7  
POSITIVE SAMPLING RESULTS FOR  
PESTICIDES IN EEWTP WATERS

<u>Date and Compound<sup>1</sup></u>	<u>Sampling Location and Concentration (µg/L)<sup>2</sup></u>		
	<u>Blended Influent</u>	<u>Filter Effluent</u>	<u>GAC Effluent</u>
12 August 1982 Gamma-BHC	0.04	ND <sup>3</sup>	ND
9 September 1982 Gamma-BHC	0.04	ND	ND
7 October 1982 Gamma-BHC	0.05	0.04	ND
28 October 1982 2,4-D	0.16	ND	ND
4 November 1982 Gamma-BHC	0.15	0.13	ND
25 November 1982 2,4-D <sup>4</sup>	ND	ND	0.24
2 December 1982 Gamma-BHC	0.03	0.03	ND
30 December 1982 Gamma-BHC	0.04	0.04	ND
6 January 1983 Gamma-BHC	0.03	0.03	ND
27 January 1983 2,4,5-TP <sup>4</sup>	ND	0.67	ND

1. Analysis by LLE except where noted.

2. Pesticides and herbicides were never quantified in EEWTP finished water.

3. Concentration was below MDL and/or IDL.

4. Analysis by LLE with methylation.

# Fate of Contaminants

TABLE 6.3-8  
SECONDARY ORGANIC COMPOUNDS DETECTED IN MORE  
THAN FIFTEEN PERCENT OF SAMPLES  
FREQUENCY OF OCCURRENCE/RANGE OF VALUES  
PHASE IIA

Parameter	Blended Influent			Filter Effluent			GAC Effluent			Finished Water		
	N	No. Quant.	Range <sup>1</sup>	N	No. Quant.	Range	N	No. Quant.	Range	N	No. Quant.	Range
Hexane	15	3	0.1	13	1	0.1	13	0	ND <sup>2</sup>	13	1	0.1
2,4,4-Trimethyl-pentane	15	2	0.2-0.3	13	2	0.2	13	1	0.2	13	0	ND
1,1-Oxybisethane	15	3	0.1-1.4	13	3	0.1-1.5	13	1	1.2	13	1	0.1
Decanoic Acid	7	0	ND	7	0	ND	7	0	ND	6	1	1.8
Dodecanoic Acid	7	0	ND	7	0	ND	7	0	ND	6	1	5
Octanoic Acid	7	0	ND	7	0	ND	7	0	ND	6	1	1.9
1-Ethyl-2-methylbenzene	14	2	0.011-0.012	9	1	0.007	13	1	0.018	10	2	0.009
1-Ethyl-4-methylbenzene	14	2	0.0076-0.012	9	0	ND	13	0	ND	10	1	0.007
1,2,3-Trimethylbenzene	14	2	0.0089-0.023	9	0	ND	13	1	0.006	10	1	0.008
1,2,4-Trimethylbenzene	14	2	0.010-0.054	9	0	ND	13	1	0.016	10	1	0.008
1,2,5-Trimethylbenzene	14	2	0.0045-0.018	9	0	ND	13	0	ND	10	0	ND
Decanal	14	2	0.012-0.026	9	1	0.028	13	1	0.032	10	2	0.013-0.092
Nonal	14	2	0.014-0.042	9	1	0.048	13	2	0.011-0.044	10	2	0.041-0.090
Heptanal	14	0	ND	9	0	ND	13	0	ND	10	4	0.0034-0.098
1-Methyl-4-(1-methylethyl)butyl-2-methylpropanoate	14	2	0.013-0.014	9	0	ND	13	0	ND	10	0	ND
2-Methylpropanoic Acid butyl ester	14	1	0.007-0.040	9	0	ND	13	0	ND	10	1	0.042
	14	1	0.060	9	1	0.700	13	2	0.030-0.900	10	2	0.040-0.058

1. All concentrations in µg/L.  
2. ND = Not Detected.

## Fate of Contaminants

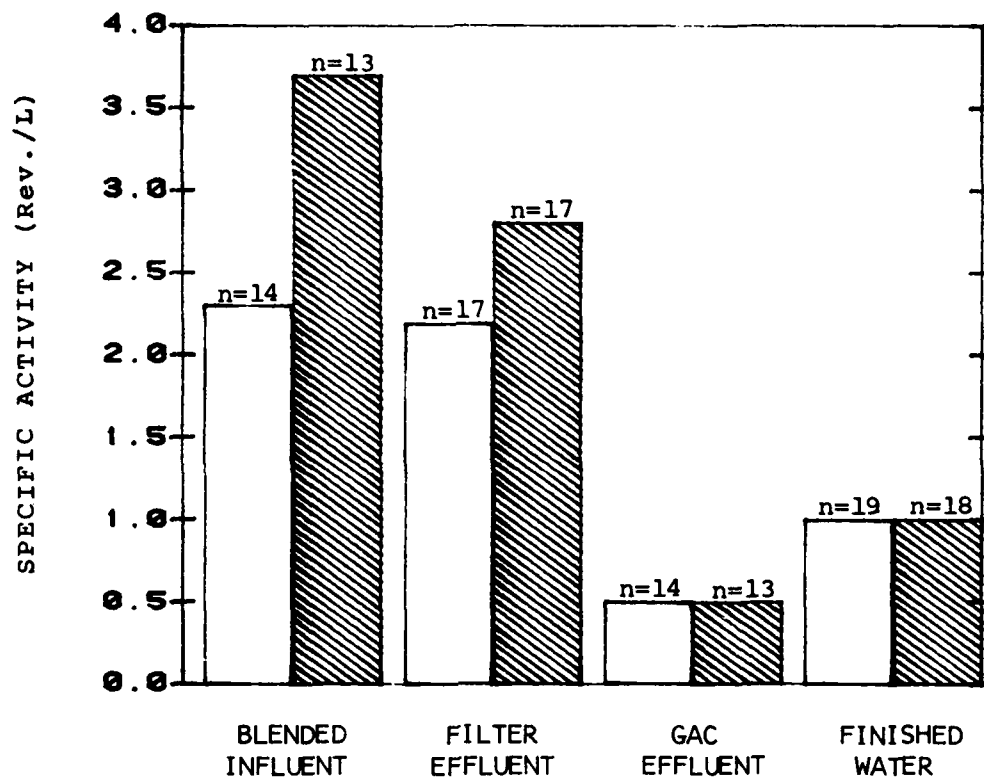
Table 8.3-8 lists those secondary organic compounds detected in more than 15 percent of the samples from at least one of the four sites listed in Figure 8.3-22. A fewer number of secondary organic compounds were frequently detected at these four sampling sites during Phase IIA than during Phases IA and IB. Only four of the seventeen compounds listed in this table were detected at concentrations greater than or equal to 1 µg/L at any sampling site. Note that the removals of secondary organic compounds can only be qualitatively evaluated. A quantitative comparison can only be made for a small number of primary organics, as discussed above.

### SUMMARY

Of the large number of organic compounds which have been detected in natural waters, a relatively small number have been identified in the EEWTP blended influent during Phase IIA. This is due to two main factors related to analytical capabilities. First, available analytical techniques were capable of detecting mostly low molecular weight, polar compounds. Second, detection limits of the techniques limited the number of compounds that could be detected. However, the MDLs for many primary compounds are on the order of 1 µg/L. For those compounds which were detected in the EEWTP blended influent during Phase IIA, the combination of unit processes through GAC appeared to provide an adequate barrier against the passage of trace organics into the finished water. Geometric mean concentrations of both surrogate and specific organic compounds of health concern were generally lower during Phase IIA, than during Phases IA and IB, as discussed in the data presented above. In addition, the unit processes in Phase IIA appeared to be more effective in removing these organic compounds.

### TOXICOLOGICAL PARAMETERS

Process trends similar to Phase IA and IB (Figures 7.3-19 and 7.3-20) for Ames test results are shown in Phase IIA process performance data in Figure 8.3-23. The mean finished water specific activities were generally lower in Phase IIA, probably as a result of using ozone and combined chlorine for final disinfection and not having an intermediate oxidant such as chlorine (Phase IA) ahead of the dual media filters.



□ = TA 98

▨ = TA 100

**SPECIFIC ACTIVITY  
IN EEWTP PROCESSES  
(PHASE IIA)  
FIGURE 8. 3-23**

## SECTION 4

### PROCESS ANALYSIS

As discussed in Chapter 7, individual processes used at the EEWTP were evaluated with respect to performance and various operational and environmental conditions. The result of these process analyses for Phase IIA are presented in this section. Processes discussed include chemical clarification with lime and ferric chloride, gravity filtration, adsorption on granular activated carbon, and disinfection with ozone and chloramines. Where appropriate, these results are the basis for selection of design criteria used in Chapter 11 to estimate costs for a full scale estuary treatment plant.

#### CHEMICAL CLARIFICATION

The chemical clarification process consisted of lime and ferric chloride addition to the water, rapid mixing to disperse the chemicals, flocculation to enhance floc formation and growth, and gravity sedimentation. Recarbonation of the water prior to gravity filtration was necessary to reduce the pH and produce a more stable water.

Although lime is not widely used as a primary coagulant in water treatment except when softening is required, it possesses attributes that met some of the needs of the EEWTP. Lime is more precisely characterized as a chemical precipitant rather than a chemical coagulant. The rise in pH caused by lime addition results in insoluble species of calcium and magnesium being formed. These precipitates enmesh and remove colloidal impurities in the water. Lime addition also results in a number of other insoluble metallic species being formed. As with alum, lime was added to remove turbidity, TOC, TOX, color, and metals from the water.

Many of the precipitates formed are in the colloidal size range and may not settle out or agglomerate to form larger flocs. Ferric chloride was added as a coagulant aid to enhance the removal of the more stable species in the water. Bench-scale testing demonstrated that a small dose of ferric chloride (2 mg/L) was sufficient to markedly enhance chemical clarification.

The high pH conditions and floc enmeshment resulting from lime addition were also of benefit in providing bacterial control. No intermediate disinfectant was used in Phase IIA. These high pH conditions, however, required recarbonation to lower the pH prior to gravity filtration.

This section provides data to describe how well the lime clarification process functioned. The impacts of various factors on process efficiency are also discussed.

## PERFORMANCE WITH RESPECT TO KEY PARAMETERS

### Turbidity and Total Suspended Solids (TSS)

During Phase IIA, approximately 75 percent of the turbidity and 55 percent of the TSS were removed by the chemical clarification process. Figure 8.4-1 show the blended influent and sedimentation tank effluent turbidities for the entire time period. The data indicate a fairly consistent removal of turbidity. The high turbidities shown in October were attributed to the ferric chloride feed being down for process evaluation and to mechanical mixing problems. Effluent turbidity remained relatively low even during periods of high influent turbidity. As with alum clarification, it is possible that turbidity removal could have been improved with better hydraulic performance in the sedimentation tank. However, the tank short circuiting was largely off-set by the highly conservative detention time of four hours, such that the majority of the influent was settled for three hours or more. Only ten percent of the water exited prior to one hour of detention.

### TOC and TOX

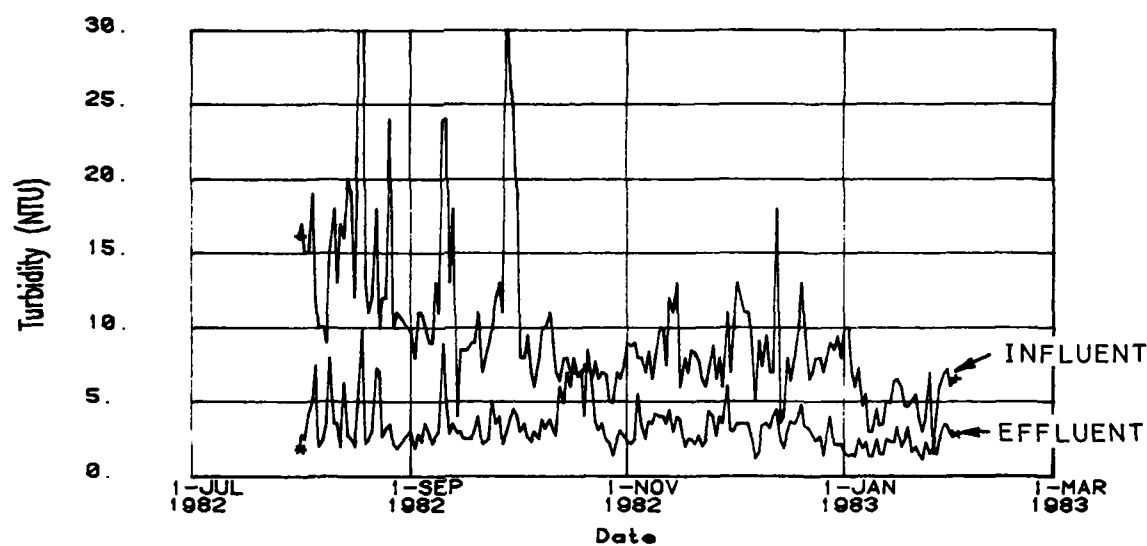
Figure 8.4-2 shows the TOC in the blended influent and sedimentation tank effluent. For the most part, TOC removal was fairly consistent throughout the time period. The chemical clarification process removed approximately 35 percent of the TOC and thirty percent of the TOX. The removed fractions of both TOC and TOX were most likely colloidal in nature, as demonstrated for the alum clarification process through bench testing. Although not specifically shown in the lime bench work, it is unlikely that the lime process would lead to enhanced removal of dissolved organics.

### Color

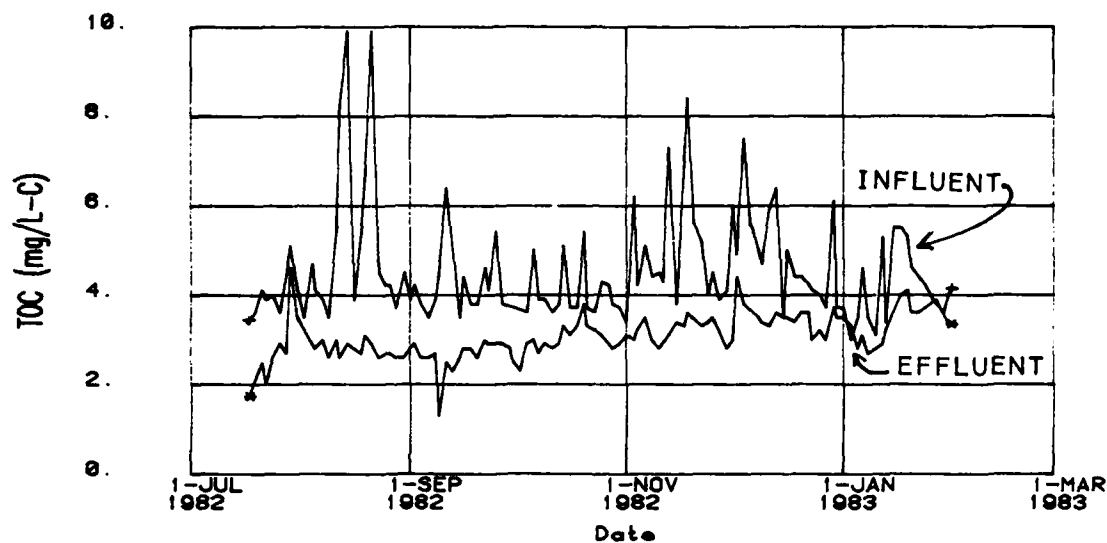
The chemical clarification process removed approximately 74 percent of the color during Phase IIA. Figure 8.4-3 shows the color in the blended influent and filter effluent during this time period. Because there was no intermediate disinfection, the entire color removal can be attributed to chemical clarification and filtration. Generally, when the blended influent color increased the filter effluent color also increased.

### Trace Metals

As shown in Section 3, trace metals were removed through lime clarification to very low levels such that trace metals were judged to be of insignificant concern for Phase IIA finished water. Data for the monitored trace metals at the blended influent locations are summarized in Table G-3-4 of Appendix G. Although influent levels are generally too low to permit accurate quantitative evaluation of the different periods of operation, the data do illustrate the generally good removal of trace metals which was achieved, most of which occurred through chemical clarification.

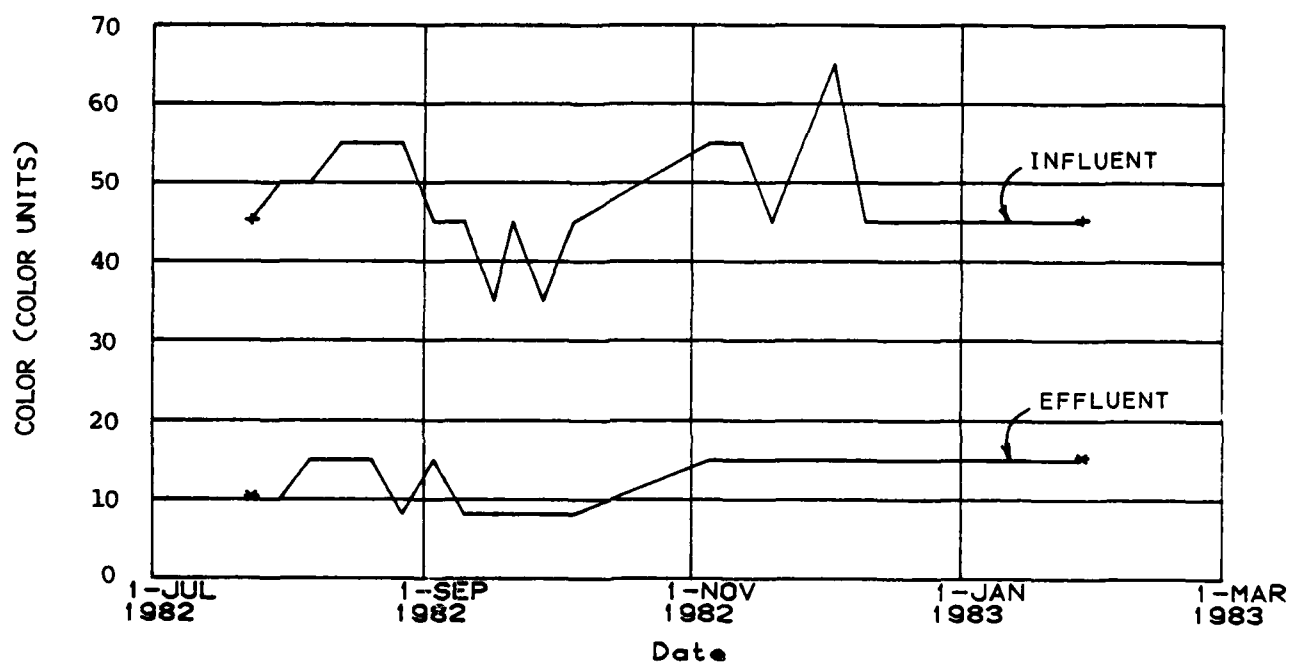


**CHEMICAL CLARIFICATION  
INFLUENT AND EFFLUENT TURBIDITY  
(PHASE IIA)  
FIGURE 8. 4-1**



**CHEMICAL CLARIFICATION INFLUENT AND EFFLUENT TOC  
(PHASE II A)  
FIGURE 8. 4-2**





**CHEMICAL CLARIFICATION  
INFLUENT AND EFFLUENT COLOR  
(PHASE IIA)  
FIGURE 8. 4-3**

## Process Analysis

### Microbiological

Chemical clarification with lime was responsible for a 2.2 log reduction in the geometric mean concentration (MPN) of coliform bacteria. The data also show a 1.1 log reduction in Standard Plate Count.

### Hardness

One concern with the use of lime is the addition of calcium hardness to the treated water. Alkalinity in the blended influent was generally in the range of 65 to 75 mg/L- $\text{CaCO}_3$ . Therefore, the carbonate for precipitation of calcium (as  $\text{CaCO}_3$ ) was somewhat limited. At the operating pHs utilized (10.5 to 11) there was an average hardness in the filter effluent of 220 mg/L- $\text{CaCO}_3$ . This was an increase of 33 percent over the average hardness of 165 mg/L in the blended influent.

It should be noted that the average hardness of 220 mg/L in the filter effluent included operating periods when the lime process was operated at pHs of 11.2 and higher. If a full-scale plant were operating at something other than a high-lime treatment mode, then the increase in hardness would be somewhat less. Nonetheless, any water with hardness levels greater than 150 mg/L- $\text{CaCO}_3$  may be considered as reasonably hard and certain water uses may be affected. In particular, soap consumption will increase for cleansing applications and scaling should be anticipated whenever the water temperature is sufficiently increased (boilers, hot water pipes, etc.). The question as to whether or not softening processes should be considered is related to the economic concerns associated with water usage for purposes other than drinking. As discussed in Chapter 9, there are numerous water supplies across the U.S. with hardness levels well above those observed in the EEWTP finished water.

## PROCESS VARIABLES AND IMPACT ON PERFORMANCE

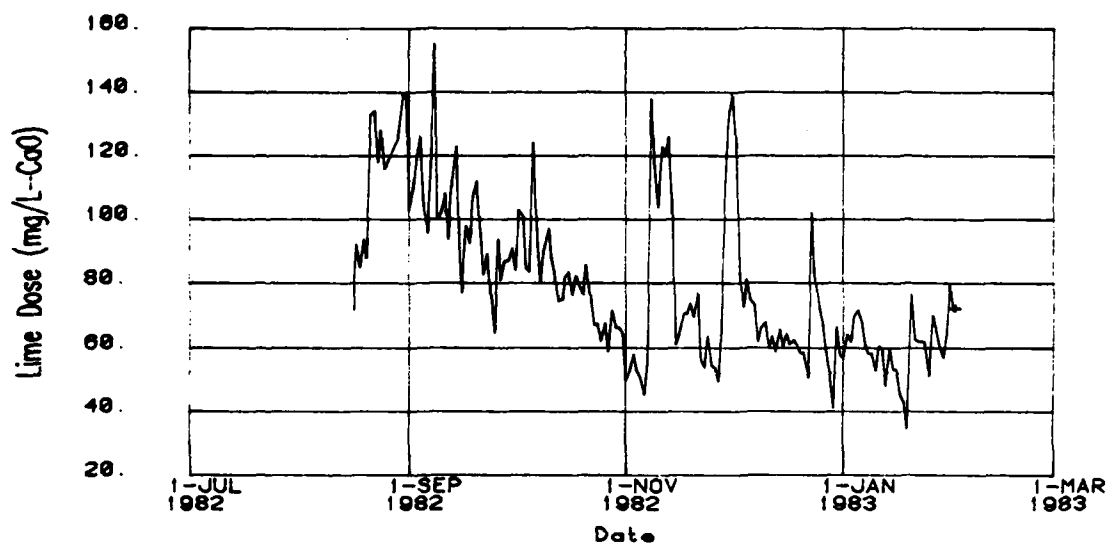
### Temperature

The results did not seem to indicate that temperature markedly affected removals of TOC, TOX, color, and trace metals. As was shown in Section 2, the water temperature decreased from September 1982 to February 1983. Observations on the appearance of the chemical floc formed in the flocculation process, indicated a visible decrease in floc size at colder water temperatures, but significant changes in turbidity removal were not observed.

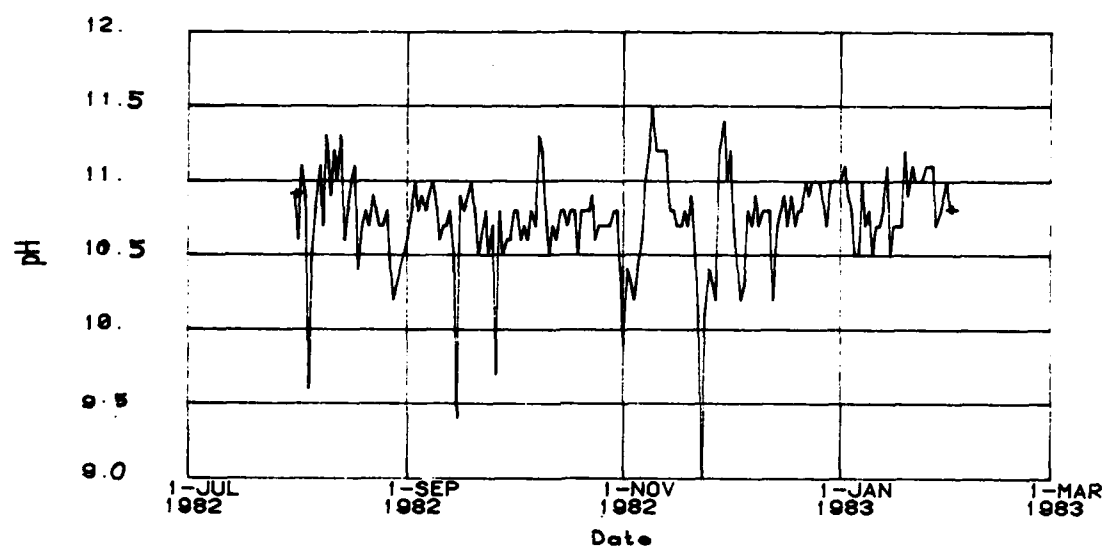
### Lime Dose

The intent was to run the EEWTP at a pH between 10.5 and 11.0. Figures 8.4-4 and 8.4-5 show the lime dose and resulting pH for the operating period. Figures 8.4-1 and 8.4-2 illustrate that the change in lime dose had little direct correlation with turbidity or TOC removal.

To better understand the effects on process performance of different lime doses (and resulting pHs), a six-week testing program was conducted from 25 October until 4 December 1982. The three operating pHs used for the study



**APPLIED LIME DOSE  
(PHASE II A)  
FIGURE 8. 4-4**



**LIME COAGULATION PROCESS pH  
(PHASE II A)  
FIGURE 8. 4-5**

## Process Analysis

were 10.3, 10.7, and 11.2. During this time, each pH was tried for two one-week periods, alternated to minimize the effects of variable influent water quality and temperature. The results indicated 17, 24, and 28 percent removal of TOC at the three increasing pH levels. Greater coliform removals were noted with increasing pH. These apparent benefits, however, were offset by increased hardness, increased solids production, and increased chemical costs. Based upon all considerations, the mid-pH level was recommended and was maintained for the remainder of Phase II.

### Ferric Chloride

Bench-scale tests indicated that 2 mg/L of ferric chloride would give good results. These bench-scale results were confirmed in the EEWTP operating results. The benefit of ferric chloride was readily seen during several outages of the ferric chloride feed. This was especially noticed during October. The quality of the chemical floc rapidly decreased and then rapidly increased when the ferric chloride dose was resumed. Except for a few brief periods, the ferric chloride dose remained at 2 mg/L.

### Alkalinity

The average alkalinity in the blended influent was 70 mg/L- $\text{CaCO}_3$ . As anticipated, a general trend was usually seen where the lime dosage required to achieve a certain pH increased as the alkalinity of the blended influent increased. Increased alkalinity decreased the treated water hardness.

### Magnesium

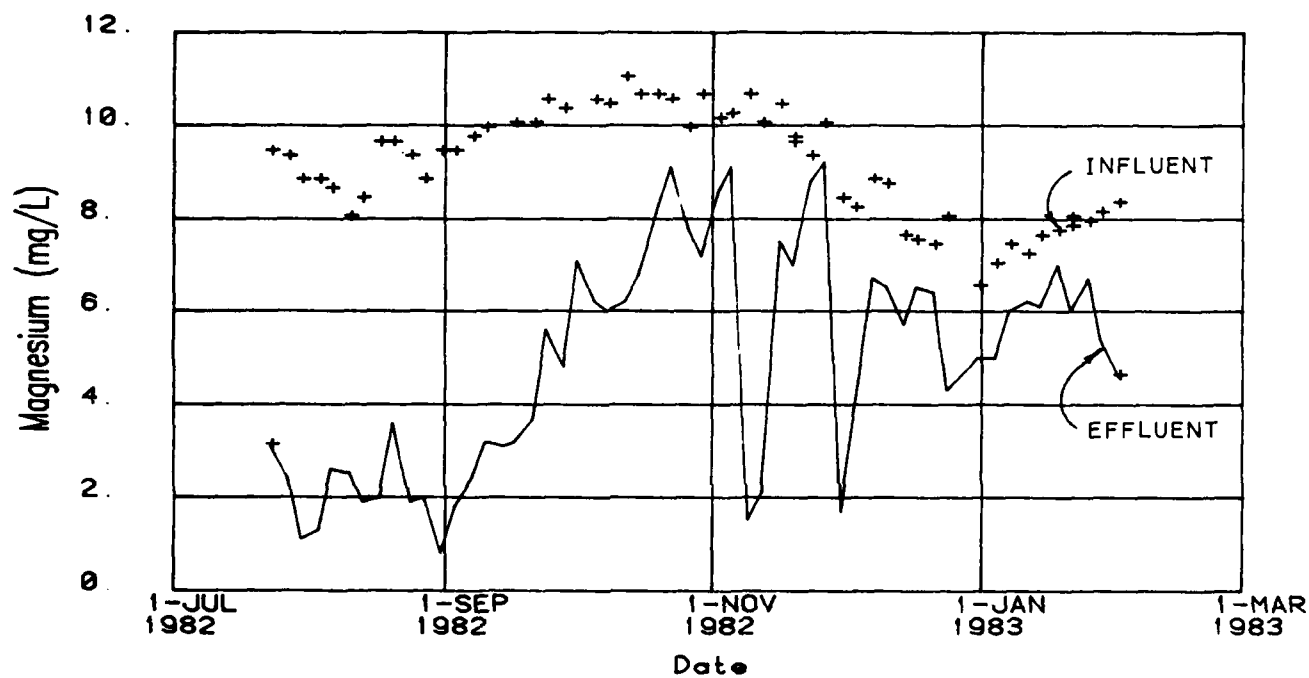
Figure 8.4-6 shows the magnesium in the blended influent and filter effluent. Magnesium is removed as the insoluble hydroxide. Removal of magnesium becomes more noticeable as the pH rises over 11. The magnesium hydroxide formed aids in the removal of small colloidal particles and has been attributed with increasing TOC removal. During the periods of high-lime testing in mid and late November, the effect on increased magnesium removal was seen. Greater magnesium removal was seen whenever the lime dose was increased. Somewhat increased TOC removals were also observed during these high pH conditions.

### Recarbonation

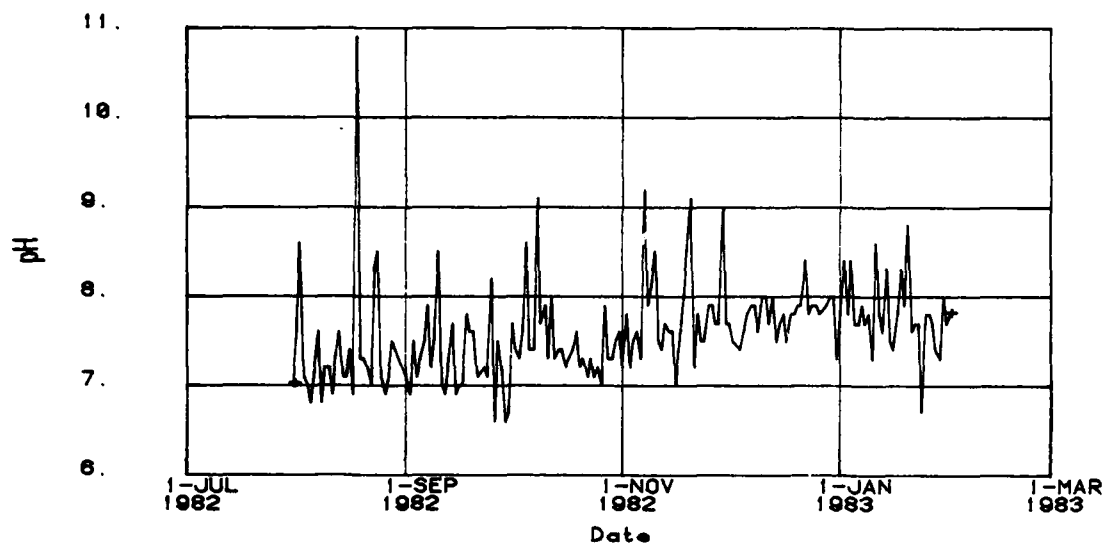
The intent of the recarbonation process was to maintain the pH in the range from 7.5 to 8.0. This would result in a water with a slightly positive Langelier Index. Figure 8.4-7 shows the recarbonation effluent pH for the period. As expected, the time-series plot of  $\text{CO}_2$  dose looked similar to the plot of lime dose. Higher doses of  $\text{CO}_2$  are an additional factor related to the higher costs of maintaining higher effluent pH with lime clarification.

### Solids Production

As previously mentioned, more solids were produced at higher lime doses. Solids production averaged approximately 2,200 lb/MG when operating at a pH



**CHEMICAL CLARIFICATION  
INFLUENT AND EFFLUENT MAGNESIUM  
(PHASE IIA)  
FIGURE 8. 4-6**



**RECARBONATION EFFLUENT pH  
(PHASE II A)  
FIGURE 8.4-7**

## Process Analysis

of approximately 10.8. Solids production increased over thirty percent when operating at a pH of 11.2. The solids concentration of the lime sludge was approximately 5.0 percent.

### GRAVITY FILTRATION

The gravity filters were evaluated based on two criteria: filtered water quality and net water production.

#### FILTERED WATER QUALITY

##### Turbidity

The filtered water turbidity is an indication of how well the filtration process is removing particulate matter. Figure 8.4-8 is a plot of the turbidity of the influent to the filters and the effluent from the filters in Phase II. Unlike in Phase I, the effluent turbidity from the filters did not mirror the influent turbidity. The effluent turbidity was also more stable in Phase II than in Phase I.

The influent water turbidity geometric mean during Phase II was 2.27 NTU. The geometric mean of the filtered water was 0.11 NTU. This represents a 95 percent reduction in turbidity across the filtration process. The arithmetic mean of 0.13 NTU in the filtered water is well below the EPA Primary Drinking Water Standard of 1 NTU. Based on this standard, the gravity filters performed more than adequately during Phase II.

##### Total Organic Carbon

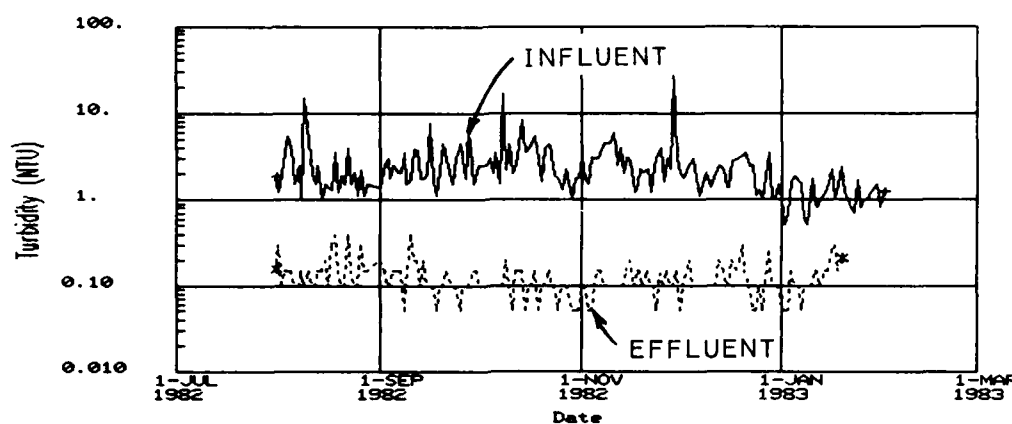
Figure 8.4-9 depicts the TOC level in the influent to the filter and in the effluent from the filters. The influent and effluent TOC curves are roughly parallel throughout Phase II. The geometric mean of the influent TOC was 3.31 mg/L-C whereas the geometric mean of the effluent TOC was 3.10 mg/L-C. Overall, this represented a six percent reduction in TOC across the filtration process. This value is nearly half the reduction value experienced during Phase I.

#### WATER PRODUCTION

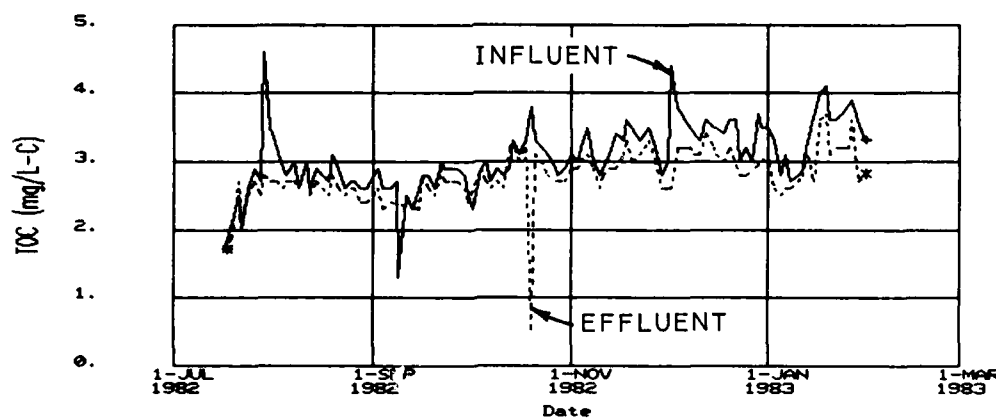
The net water produced by a filter is quantified by the unit filter run volume (UFRV). The goal of filtration is to maximize the UFRV while maintaining the quality of filtered water required. As discussed in Chapter 7, the efficiency of water production decreases when the UFRV drops below 5,000 gal/ft<sup>2</sup>/run.

Table 8.4-1 presents water production data. The average time between backwash was 85.7 hours. The average unit filter run volume was 15,925 gal/ft<sup>2</sup>/run and the average production efficiency was 99.3 percent.





**FILTRATION: INFLUENT AND EFFLUENT TURBIDITY  
(PHASE IIA)  
FIGURE 8. 4-8**



**FILTRATION: INFLUENT AND EFFLUENT TOC  
(PHASE IIA)  
FIGURE 8. 4-9**

TABLE 8.4-1  
GRAVITY FILTER WATER PRODUCTION DATA AT 3 gpm/ft<sup>2</sup> PHASE II

Month	Average Time Between Backwash (hrs)	Backwash Volume (gals)	Average Unit Filter Run Volume (gal/ft <sup>2</sup> /run)	New Water Production (Percent)
August, 1982	71	12,987	12,672	99.1
September	90	12,410	16,097	99.4
October	115	13,457	20,588	99.5
November	78	15,162	13,914	99.1
December	71	14,196	12,662	99.1
January, 1983	89	12,110	15,919	99.4
Average	85.7	13,387	15,925	99.3

## Process Analysis

These values represent an increase from Phase I production values at 3 gpm/ft<sup>2</sup>. As in Phase I, the UFRV and production efficiencies were adequate.

### GRANULAR ACTIVATED CARBON ADSORPTION

During Phase II operation, the lignite based ICI 816 carbon was replaced with the bituminous based F-400 (Calgon Corporation) carbon and the empty bed contact time (EBCT) was increased by bypassing half of the filter effluent to waste. Thus, the lead column had an EBCT of 15 minutes, with a total EBCT of 30 minutes. Surface loading rate was approximately 4.5 gpm/ft<sup>2</sup>, half of that used in Phase I. Contactor performance under these conditions is discussed below.

### OVERVIEW OF GAC OPERATION

Influent and effluent concentration history profiles were presented in Figure 7.4-7(a), (b), and (c) for TOC, TOX and chloroform, respectively. The data for the two phases are presented together for perspective. All the data presented for the lime phase were from composite samples.

During Phase II, the influent TOC concentration to the GAC columns ranged between 2.4 and 3.6 mg/L. Because the effluent TOC never reached the treatment objective of 2.0 mg/L, regeneration or replacement of carbon was not conducted, and only one GAC run was made.

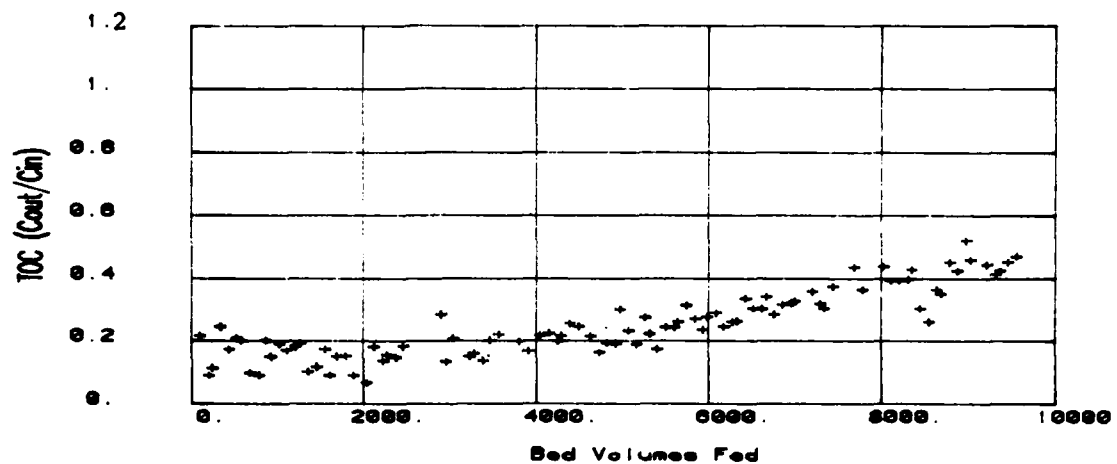
Day to day fluctuations in TOX and chloroform were not as severe as those observed in Phase I. Influent TOX concentration averaged 40 µg/L at the beginning of the phase, increasing to about 140 µg/L in December 1982. Influent chloroform concentration averaged 2 to 3 µg/L.

### REMOVAL PERFORMANCE FOR SELECTED PARAMETERS

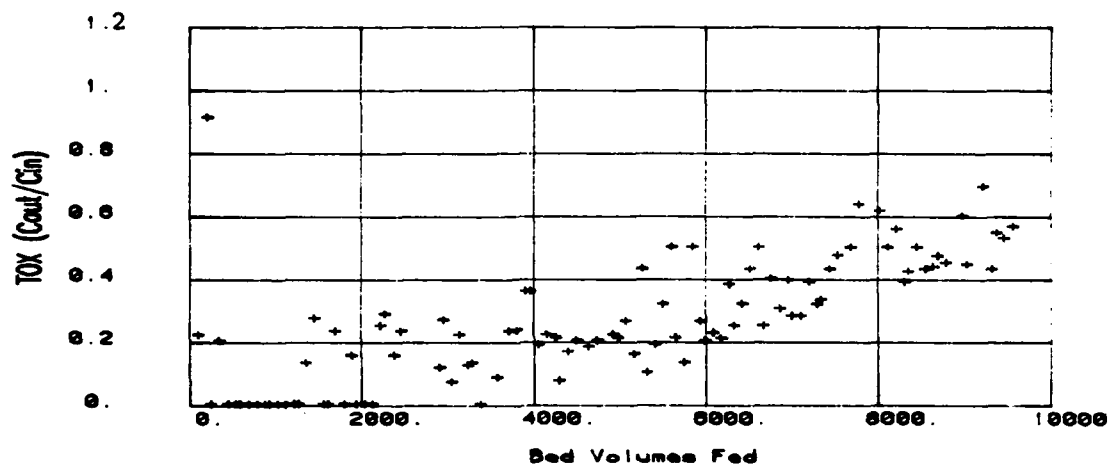
The removal performance for TOC, TOX and chloroform are presented in Figure 8.4-10(a), (b), and (c), respectively. The data are plotted in these figures in terms of bed volumes fed (BVF) versus the effluent concentration divided by the influent concentration. The data are taken from 24-hour composite samples.

Examination of TOC and TOX removal in Figures 8.4-10(a) and (b) show equal removals up to approximately 8,000 BVF, after which TOC removal appears to be slightly better. Plots of the TOC and TOX breakthrough curves for the lead column (15 minutes EBCT) are presented in Figures 8.4-11(a) and (b). These figures support the conclusion that TOC is removed slightly better than TOX. Complete exhaustion is estimated to occur at 20,000 to 25,000 BVF for TOC and TOX. Based upon the results, TOC could be used as a surrogate parameter for TOX removal.

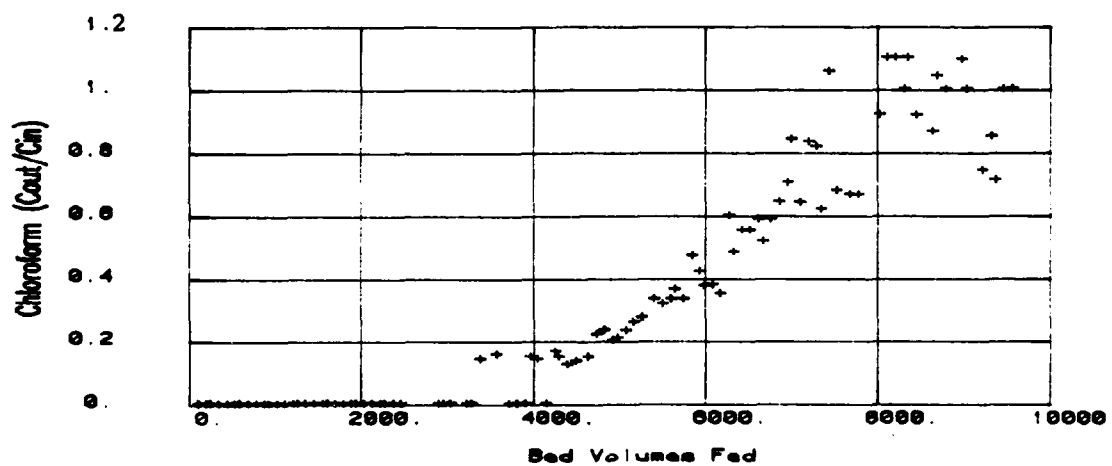
Chloroform data are presented as an example of an SOC that, in general, is less well adsorbed than other SOC's (Dobbs and Cohen, 1980). The removal performance is presented in Figure 8.4-10(c). The GAC becomes exhausted with respect to chloroform between 8,000 to 10,000 BVF, less than half the bed



(a) TOC

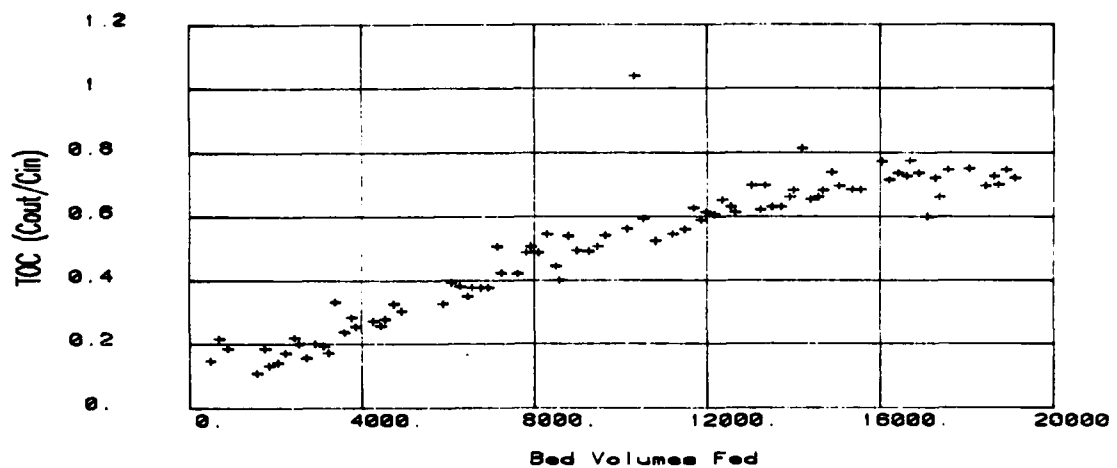


(b) TOX

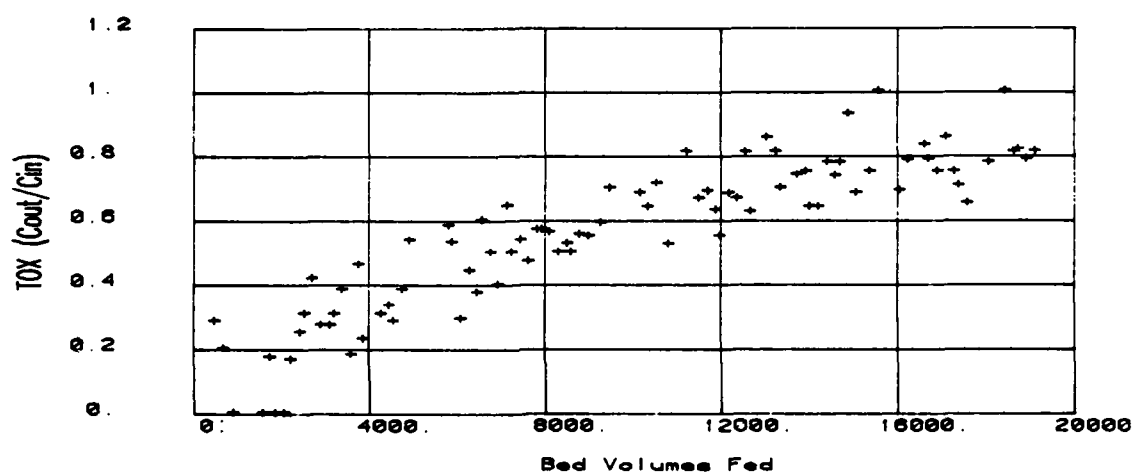


(c) Chloroform

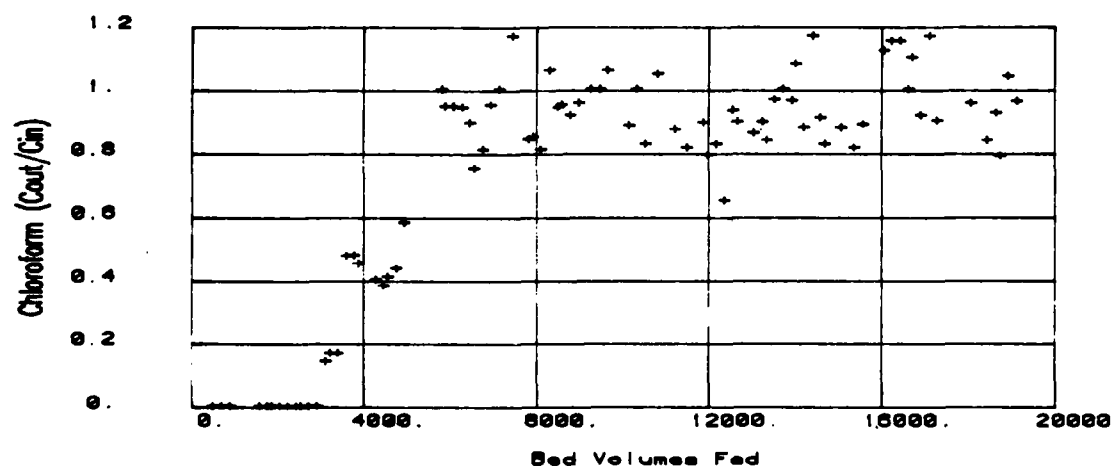
REMOVAL PERFORMANCE FOR  
TOC, TOX AND CHLOROFORM  
30 MIN. EBCT  
(PHASE IIA)  
FIGURE 8. 4-10



(a) TOC



(b) TOX



(c) Chloroform

REMOVAL PERFORMANCE FOR TOC, TOX AND  
CHLOROFORM 15 MIN. EBCT  
(PHASE II A)  
FIGURE 8.4-11

## Process Analysis

volumes required for TOC or TOX exhaustion. Given this fact, TOC would not be a conservative surrogate parameter for chloroform or other SOC's that exhibit similar breakthrough profiles. That is, continuous feed of high chloroform levels could result in unacceptable effluent levels well before TOC exhaustion occurred.

However, influent levels of chloroform were generally quite low, especially during Phase II when intermediate disinfection was not practiced. Even though the carbon's capacity may be exhausted at 8,000 BVF, a sudden increase in chloroform in the influent would result in increased adsorption capacity on the GAC because the equilibrium capacity increases with increasing influent concentration. Therefore, if a spill event occurred, the carbon would be expected to adsorb the additional chloroform, thereby performing as an effective barrier to SOC's. Monitoring of the adsorber influent and effluent is necessary to determine when a spill event occurs, and when the adsorber should be regenerated should such events occur.

### CARBON USAGE RATE

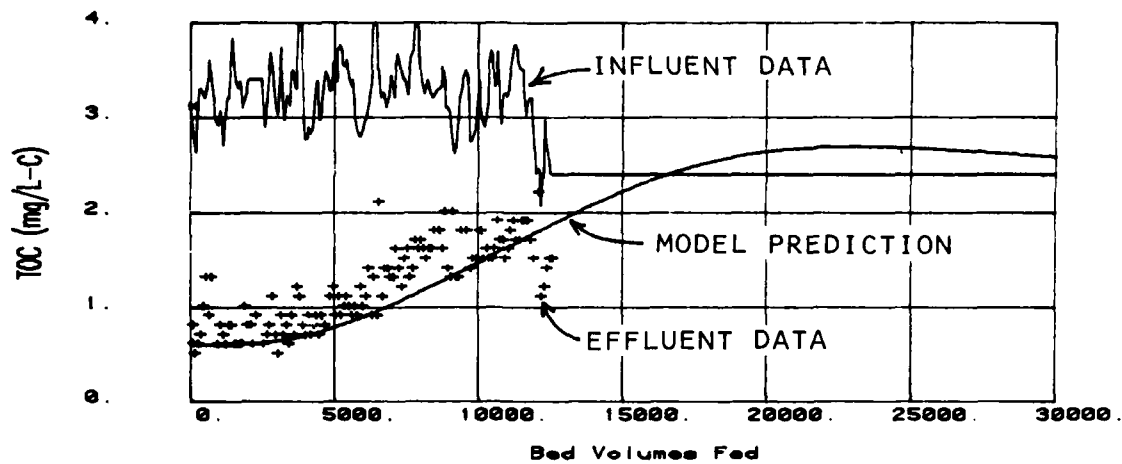
As previously described in Chapter 7, Section 4, the HSDM model was used to determine carbon usage rates for different empty bed contact times and treatment objectives. The model was calibrated (see Chapter 10, Section 3) to data obtained from pilot scale adsorbers, and verified by predicting the plant scale data. The model was verified using the 15 minute EBCT (lead) column from plant scale operation. The results, presented in Figure 8.4-12(b) show that the model predicts the data as well as it did for the calibration run, shown in Figure 8.4-12(a). Furthermore, the model predicted the data for a 30 minute EBCT, shown in Figure 8.4-12(c), demonstrating its ability to predict breakthrough profiles for different EBCTs.

During Phase II operation, almost 18,000 lbs of carbon were used to treat the water. This represents a carbon usage rate of 350 lbs of GAC per million gallons of water treated. However, as discussed in Chapter 7 for Phase I, the actual carbon usage rate experienced at the EEWTP probably did not reflect the usage rates that would be experienced at a full-scale plant. These latter are discussed more fully in Chapters 10 and 11.

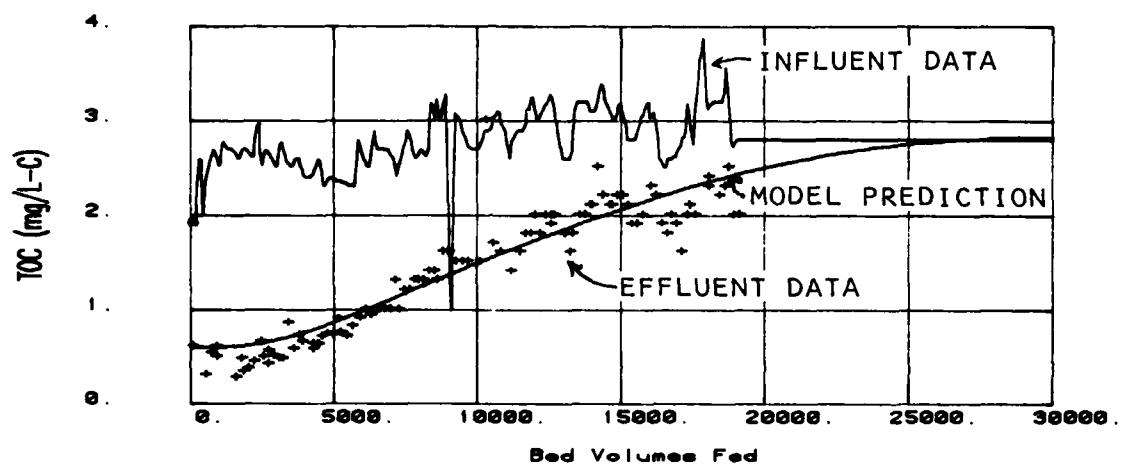
### PROCESS PERFORMANCE AND RELIABILITY

Time series plots of pH, temperature and major cation concentrations have been presented in Figures 7.4-12(a), (b) and (c), respectively. The pH increased gradually from near 7.0 to almost 8.0. Day to day fluctuations were sometimes one pH unit or more. The data ranged from 7.5 to 9.0. Influent water temperature gradually decreased from a high of 30°C to 9°C during the same time period. The calcium concentration varied greatly, ranging from 30 mg/L to 120 mg/L. Changes in lime dose contributed to the variability of the data. Aluminum and magnesium concentrations remained stable, with aluminum below 50 µg/L and magnesium below 10 mg/L.

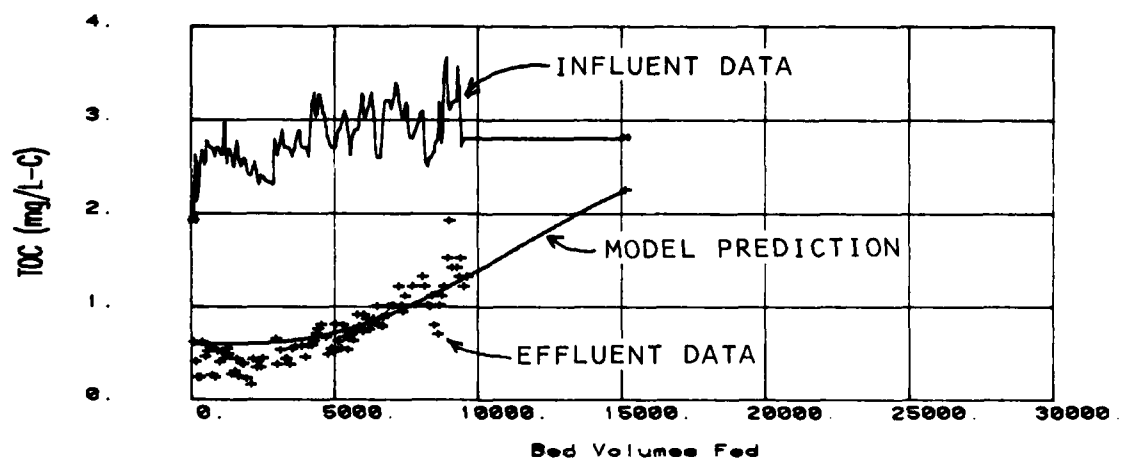
The impact that variations in these parameters had on the removal of TOC by GAC appears to be insignificant. The removal performance curve for TOC,



(a) HSDM calibration using pilot column data, 15 min EBCT.



(b) HSDM verification run with plant data, 15 min EBCT.



(c) HSDM prediction of plant data, 30 min EBCT.

# HSDM MODELING RESULTS (PHASE II) FIGURE 8. 4-12

## Process Analysis

shown in Figure 8.4-10, is characterized by not exhibiting any sharp peaks, especially when compared to Phase I breakthrough profiles. The variations that existed in influent water quality were not severe enough to cause displacement of TOC from the GAC. Unlike during Phase IA, backwash criteria during Phase II were consistently based on headloss alone, such that frequent disruption of the GAC bed did not occur.

### MICROBIOLOGICAL ACTIVITY

Cumulative probability distribution plots for total coliforms and SPC are presented in Figures 8.4-13(a) and (b), respectively. The results for SPC show a decrease across the adsorbers. This finding is surprising and the reason for it is unknown. The results for total coliform generally show an increase in coliforms across the columns.

### DISINFECTION

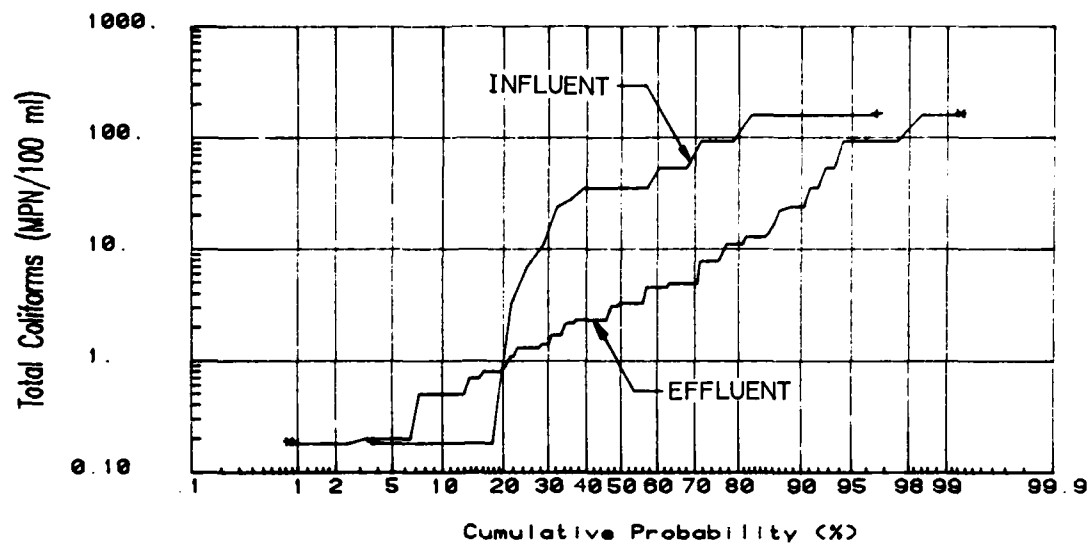
Effluent from the carbon columns was disinfected with ozone followed by residual disinfection with chloramines. Ozone was applied in the downflow passes (one and three) in a four pass vertical serpentine contactor. Detention time was 22 minutes at 0.25 MGD. The average applied dose was 1.3 mg/L  $O_3$  and the average ozone residual was 0.2 mg/L. An average ammonia dose of 1.5 mg/L-N was fed to the ozonated effluent and followed by injection of chlorine at an average dose of 4.9 mg/L  $Cl_2$ . The combined chlorine residual averaged 3.0 mg/L and the chloramination detention time was 110 minutes at 0.25 MGD.

Ozonation followed by chloramination was the most effective disinfection combination studied during the EEWTP project. Phase IIA total and fecal coliform isolations and concentrations were lower than in the previous two phases (see Chapter 9, Section 6). Phase IIA coliform results met EPA MCL regulations, NAS recommended criteria for potable reuse, and AWWA operational goals.

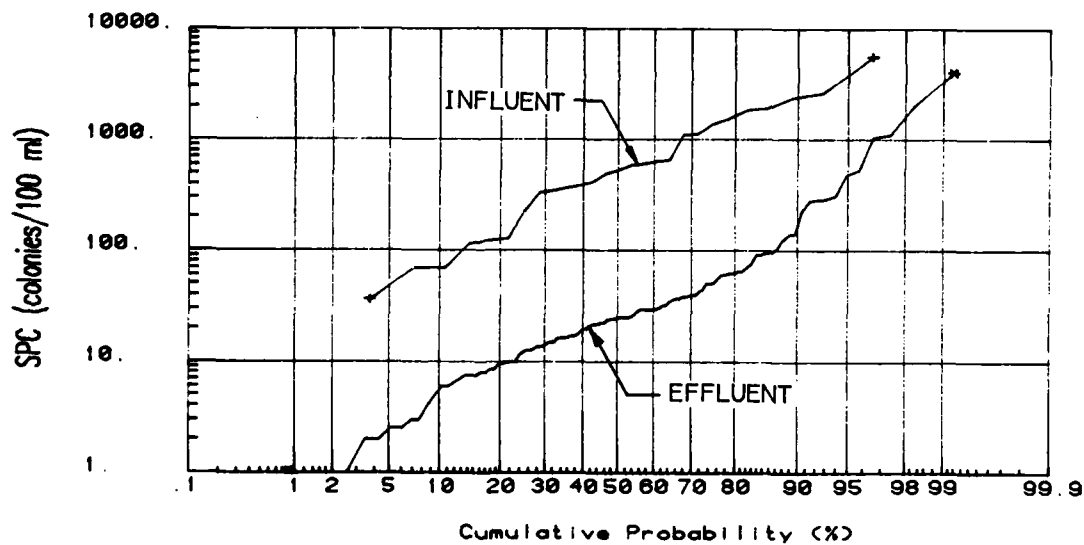
### OZONATION

Ozonation by itself did not produce a microbiological effluent quality as good as the local MWA water treatment plants with respect to total coliforms and SPC. The ozonated product water was generally better than the EEWTP finished water in Phase IA and IB for total coliforms as shown in Table 8.4-2 and worse for SPC bacteria (Table 8.4-3).





(a) Total coliforms



(b) Standard plate count

**PROBABILITY DISTRIBUTION OF TOTAL COLIFORMS AND  
SPC IN GAC INFLUENT AND EFFLUENT  
(PHASE IIA)  
FIGURE 8. 4-13**

# Process Analysis

TABLE 8.4-2

## COMPARISON OF TOTAL COLIFORMS IN THE OZONATED EFFLUENT WITH PHASE IA AND IB EEWTP FINISHED WATERS

	<u>Phase IIA Ozone Tank Effluent</u>	<u>Phase IA Finished Water</u>	<u>Phase IB Finished Water</u>
No. of Samples	93	255	68
% Positive Samples	38 <sup>1</sup>	65	28
G.M. MPN/100 ml	0.001	0.031	0.008
Median MPN/100 ml	<0.02	0.02	<0.02
90% Value	0.05	0.14	0.04
G.M. Log Removal <sup>1</sup>	3.5	2.0	3.1

TABLE 8.4-3

## COMPARISON OF SPC IN THE OZONATED EFFLUENT WITH PHASE IA AND IB EEWTP FINISHED WATERS

	<u>Phase IIA Ozone Tank Effluent</u>	<u>Phase IA Finished Water</u>	<u>Phase IB Finished Water</u>
No. of Samples	86	258	75
% Positive Samples	34	22	21
G.M. MPN/100 ml	0.5	0.2	0.4
Median MPN/100 ml	<1.0	<1.0	<1.0
90% Value	8.0	2.0	2.0
G.M. Log Removal <sup>1</sup>	1.7	2.8	2.6

1.  $\text{Log}_{10}$  (GAC effluent geometric mean + ozonated effluent or finished water geom. mean).

## Process Analysis

The NAS recommended potable reuse criteria for total coliforms at <1/100 ml at least 98 percent of the time and <1/1000 ml 90 percent of the time was met by ozonating the carbon column effluent. The 90 percent and 98 percent concentrations in the ozonated effluent were 0.05/100 ml and 0.08/100 ml, respectively. The time series plot of total coliforms in the ozonated effluent and applied ozone (Figure 8.4-14) indicates that a high quality water was produced until the applied dose began to decrease beginning in early December 1982. The reason for the decrease in applied dose has been discussed in Section 1 of this chapter. Table 8.4-4 divides the Phase IIA total coliform data into three time periods: 5 August 1982 to 30 November 1982; 1 December 1982 to 1 February 1983; and 5 August 1982 to 4 February 1983, for the complete Phase IIA results. Figure 8.4-15 is a time series plot of residual ozone in the ozonated effluent and total coliforms from the same location. The plot shows a similar trend as observed in Figure 8.4-14 for applied ozone.

TABLE 8.4-4

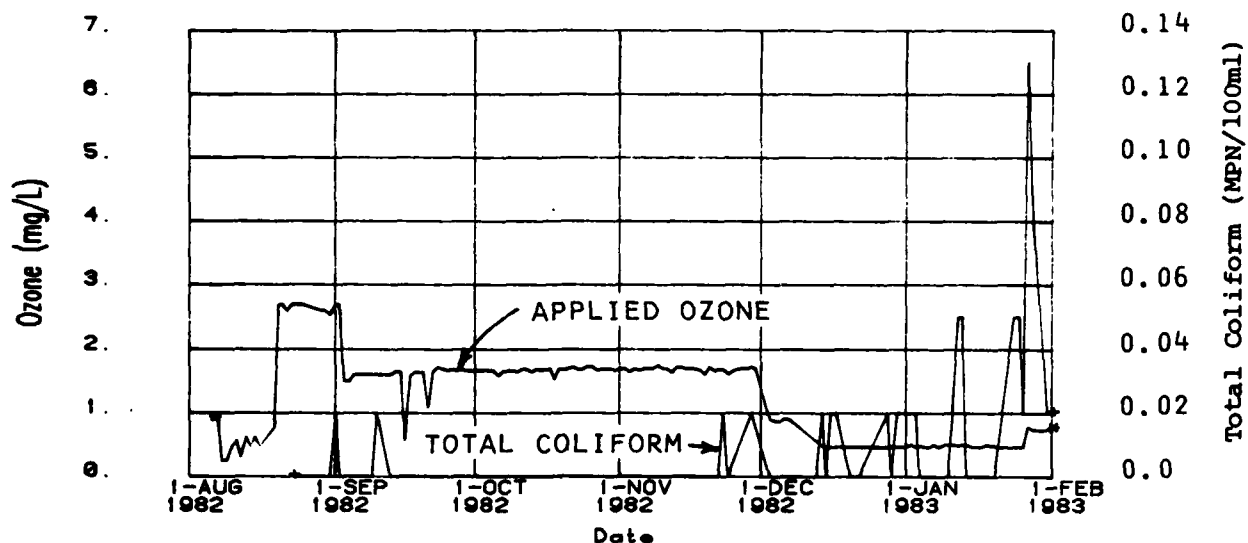
### IMPACT OF APPLIED OZONE DOSE ON TOTAL COLIFORM DISINFECTION

EEWTP Ozonated Effluent	5 Aug. 1982- 30 Nov. 1982	1 Dec. 1982- 1 Feb. 1983	5 Aug. 1982- 1 Feb. 1983
Average Applied Ozone (mg/L O <sub>3</sub> )	1.6	0.5	1.3
Average Ozone Residual (mg/L O <sub>3</sub> )	0.3	0.01	0.2
Geom. Mean (MPN/100 ml)	a	0.020	0.001
Median Total Coliform	<0.02	0.02	<0.02
% Positive Samples	7	57	26

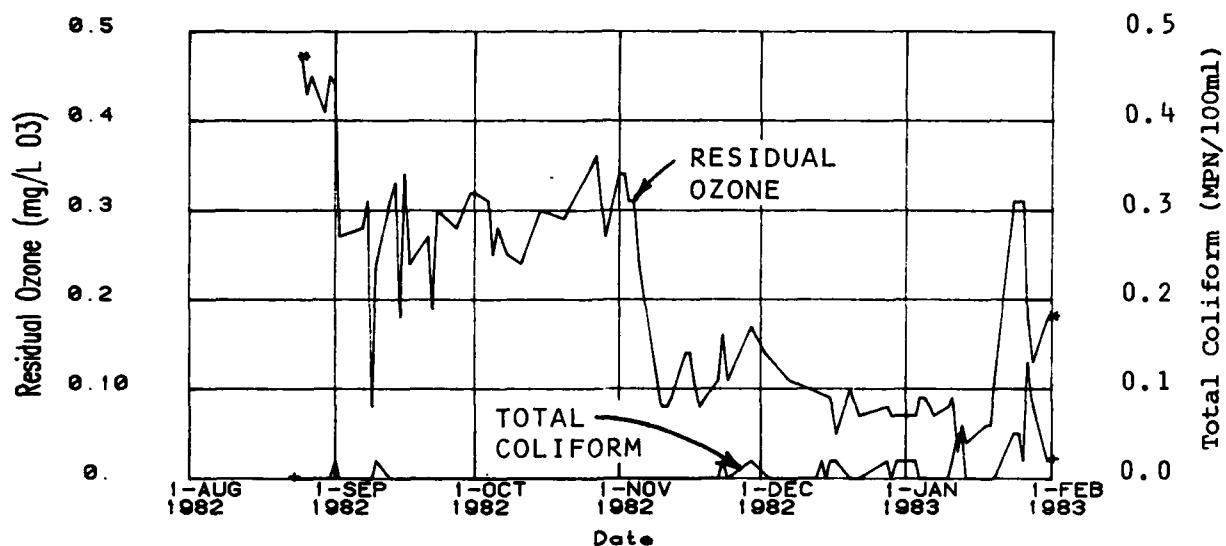
- a. Calculation of geometric mean by the EM algorithm requires 15 percent of the values to be above the detection limit.

## CHLORAMINATION

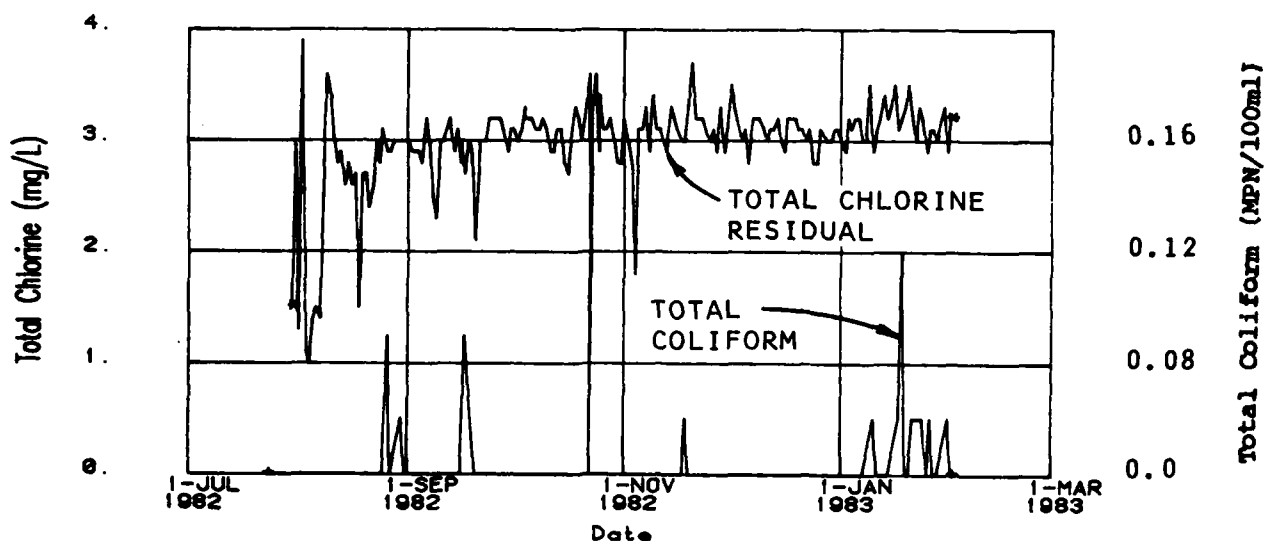
In addition to acting as a residual disinfectant during hypothetical distribution of the finished water, chloramines effectively reduced the levels of total coliforms and SPC bacteria after ozonation, as described in Section 3 of this chapter. A comparison of Table 8.4-4 to Table 8.4-5, which shows the impact of chloramination during three time periods of Phase IIA, reveals that during the period of decreasing applied ozone (1 December 1982 - 1 February 1983) the chloramine concentration was able to reduce the ozonated effluent total coliform geometric mean concentration of 0.02 to 0.009 in the finished water. The percentage of positive samples was also reduced by chloramination from 57 in the ozonated effluent to 17 in the finished water. Figure 8.4-16 is a time series plot of chlorine residual and total coliforms in the finished water.



**APPLIED OZONE DOSE AND TOTAL COLIFORMS  
IN OZONATED EFFLUENT  
(PHASE IIA)  
FIGURE 8. 4-14**



**RESIDUAL OZONE AND TOTAL COLIFORMS  
IN OZONATED EFFLUENT  
(PHASE IIA)  
FIGURE 8. 4-15**



**FINISHED WATER  
TOTAL CHLORINE RESIDUAL  
AND TOTAL COLIFORMS  
(PHASE IIA)  
FIGURE 8. 4-16**

# Process Analysis

TABLE 8.4-5

## IMPACT OF CHLORAMINATION ON TOTAL COLIFORM DISINFECTION

<u>EEWTP Finished Water</u>	<u>5 Aug. 1982- 30 Nov. 1982</u>	<u>1 Dec. 1982- 1 Feb. 1983</u>	<u>5 Aug. 1982- 1 Feb. 1983</u>
Average Total Chlorine Residual (mg/L)	2.9	3.1	3.0
G.M. (MPN/100 ml)	a	0.009	a
Median (MPN/100 ml)	<0.02	<0.02	<0.02
% Positive Samples	5.7	17	10

- a. Calculation of geometric mean by the EM algorithm requires 15 percent of the values to be above the detection limit.

## **CHAPTER 9**

### **EVALUATION OF FINISHED WATER QUALITY**

Chapters 7 and 8 dealt with describing and evaluating the performance of the plant unit processes, whereas this chapter addresses the broad characterization and evaluation of the EEWTP finished water.

The criteria utilized for evaluating finished water quality have been discussed in Chapter 1 (Section 5). The objectives of this chapter are to apply those criteria to the monitoring results collected during each major phase of EEWTP operation. EEWTP finished water is considered in the context of treating a surface source contaminated to an extent beyond that for which the federal drinking water standards were intended. In this context, it is important not only to compare EEWTP finished water to the federal regulations, but also with the drinking water as currently being supplied to the Metropolitan Washington Area (MWA). In cases where a parameter is of special health or aesthetic concern, and concentrations in EEWTP finished water are higher than observed at local WTPs, the significance of the EEWTP results are discussed in the context of potential consumer impact.

Following a general discussion of the monitoring data and strategy utilized for evaluation (Section 1), finished water quality is discussed with respect to various groups of water quality parameters. An overview of the results and general summary of the findings is provided at the end of this chapter (Section 9).



## **SECTION 1**

### **MONITORING DATA USED FOR EVALUATION**

#### **INTRODUCTION**

The purpose of this section is to describe:

1. Sampling periods utilized to characterize the EEWTP finished water during the alum and lime phases of operation.
2. Sampling periods utilized to characterize the local finished waters in the Metropolitan Washington Area (MWA).
3. The selected parameters, of the over two hundred routinely monitored, considered to be the most critical in evaluating the finished water quality.
4. The source and nature of the statistical information utilized in the evaluation.

#### **MONITORING PERIODS**

##### **EEWTP FINISHED WATER**

Because different process combinations were evaluated during the various phases of operation, the finished water from each phase was characterized separately.

##### **Alum Phases - Phases IA and Phase IB**

Data utilized to characterize the alum phase finished water were obtained from routine monitoring conducted at the EEWTP between 16 March 1981 and 6 July 1982, inclusive. During this period the EEWTP was operated with the following process train, as discussed in Chapter 7:

- Mechanical surface aeration
- Chemical clarification with alum and polymer
- Intermediate oxidation (either chlorine or ozone)
- Dual media gravity filtration
- Downflow GAC adsorption (15 minute empty bed contact time with a lignite based carbon)
- Disinfection with free chlorine (60 minute contact time)

Chlorine was utilized as the intermediate oxidant for the first twelve months of operation. Because of the potential implications with respect to both process design and water quality, the switch to ozone on 17 March 1982 was considered to constitute a new process train. Finished water quality for these periods has

## Monitoring Data Used For Evaluation

been characterized separately from the first twelve months of operation in the statistical summaries of Appendix G and H, as summarized below:

- Phase IA. 16 March 1981 to 16 March 1982. Chlorine as intermediate oxidant. Summary data found in tables of Appendix G-1 and in column 1 of tables in Appendix H.
- Phase IB. 17 March 1982 to 6 July 1982. Ozone as intermediate oxidant. Summary data found in tables of Appendix G-2 and in column 2 of tables in Appendix H.

It should be noted that, for most parameters, the change in intermediate oxidant had little or no effect upon the plant performance. The results from the longer Phase IA period are often indicative of water quality for both alum phases. In cases where a parameter is of special interest and/or differences in effluent quality are observed during Phase IB, results from the two phases are examined separately. Otherwise, separate discussion of Phase IB is not presented.

### Lime Phase - Phase IIA and Phase IIB

Data used to characterize the lime phase finished water were based on routine plant monitoring conducted between 16 March 1982 and 1 February 1983 (Phase IIA). During this period, the EEWTP was operated with the following process train, as discussed in Chapter 8:

- Chemical clarification with lime, using ferric chloride as a coagulant aid.
- Recarbonation
- Gravity filtration.
- Downflow GAC adsorption (30 minute empty bed contact time with a bituminous based carbon).
- Disinfection with ozone, followed by chloramination (120 minute contact time).

Monitoring results from this period of operation are statistically summarized in the tables of Appendix G-3 and in Column 3 of tables in Appendix H.

Further monitoring of the EEWTP finished water under lime operation was conducted between 1 February 1983 and 16 March 1983 (Phase IIB), but complete evaluation was not possible within the given time constraints. The results from this period are summarized in the tables of Appendix G-4. It should be noted that the Phase IIB results include data from a period of operation (23 February to 16 March 1983) during which free chlorine (as opposed to chloramines) was utilized as the final disinfectant after ozonation.

## MWA DRINKING WATER

Data utilized to characterize current MWA drinking water were based on samples taken from three local water treatment plants (WTPs). A general overview of the local plants was presented in Chapter 1. Finished water from these local WTPs was routinely monitored for a variety of parameters as described in Chapter 3. To characterize these waters, data from the entire sampling period, 16 March 1981 to 1 February 1983 were used. The three local plants represent the three major water suppliers in the MWA and are identified as WTP1, WTP2, and WTP3. Monitoring results from these plants are statistically characterized in columns 4, 5 and 6 of the tables in Appendix H.

### FINISHED WATER QUALITY PARAMETERS SELECTED FOR CLOSER EVALUATION

The evaluation level for any given water quality parameter is tied closely to the known or suspected significance of that parameter with respect to health effects and/or aesthetic considerations.

The various parameters investigated are described below.

1. All monitored parameters are reviewed for unusually high or especially significant results. Median values are compared and generalized findings are discussed.
2. For those parameters regulated by the National Interim Primary Drinking Water Regulations (NIPDWR) (EPA, 1975), the levels in the EEWTP finished water are compared to the established Maximum Contaminant Level (MCL). For parameters specified in the National Secondary Drinking Water Regulations (EPA, 1979a), levels in the EEWTP finished water are compared to the Secondary MCL (SMCL).
3. For all regulated parameters and other selected parameters of known or suspected health concern, results for the EEWTP finished water and the three monitored MWA water treatment plants (WTP1, WTP2, and WTP3) are compared.
4. For parameters of special health or aesthetic concern and for which the EEWTP finished water levels are higher than those in all of the local plants, the significance of the results are evaluated. This includes discussion of available health risk information, review of available information from other supplies, and comparison with alternative criteria. The latter includes the alternative goals and standards discussed in Chapter 1, Section 5.

## Monitoring Data Used For Evaluation

This discussion is needed whenever the EEWTP finished water cannot be demonstrated to be "better"<sup>1</sup> than at least one of the other plants with respect to a given parameter. Discussions may also be warranted if there are higher observed values in the EEWTP finished water, even though the central tendency is less.

Such discussion is required even where EEWTP finished water meets an established standard. The drinking water standards were not intended for use in situations where source water is highly contaminated with wastewater.

The "critical" parameters requiring more detailed evaluation are discussed for each parameter group below. Although any of these may be of concern if present in high concentration, those cited below are recognized as being of interest in the drinking water industry and have been selected for an increased level of evaluation compared to other parameters monitored.

### PHYSICAL/AESTHETIC PARAMETERS

Turbidity is the only physical/aesthetic parameter which is regulated through the NIPDWR. However, there are secondary MCLs for pH, apparent color, MBAS (foaming agents) and odor. In addition, there has been recent concern with respect to the potential health effects associated with asbestos fibers in drinking water. Taste, like odor, is of special interest with respect to the aesthetic appeal of the water. Thus, these parameters have been selected for closer evaluation, beyond the general review provided for all monitored parameters.

### MAJOR CATION, ANION, AND NUTRIENT PARAMETERS

In this parameter group, primary MCLs have been promulgated only for fluoride and nitrate. Secondary MCLs exist for total dissolved solids, chloride and sulfate.

In addition, sodium and cyanide exhibit potential undesirable health effects over certain levels, although no MCLs have been established at this time. Bromide is of interest because of its impact on the formation of halogenated organics during disinfection. Calcium, magnesium, and hardness are of special interest because of their relation to the aesthetic quality of the water as well as their potential impact on cardiovascular disease. Ammonia nitrogen is of interest because of its relationship to disinfection chemistry and odor potential.

1. Comparison is based on statistical testing of the hypothesis that the EEWTP finished water geometric mean is below that of the local plant. A "significant" difference exists if the null hypothesis (that the two populations have the same geometric mean) is not accepted at the 0.05 significance level. Thus, there is 95 percent probability that rejection is appropriate.

## Monitoring Data Used For Evaluation

### TRACE METAL PARAMETERS

Eight trace metals are included in the NIPDWR: arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. In addition, there are secondary

MCLs for copper, iron, manganese, and zinc. Five additional metals were also selected for closer evaluation, based on the potential for chronic health effects at low concentrations. They were antimony, beryllium, nickel, thallium, and tin.

### RADIOLOGICAL PARAMETERS

Gross alpha, gross beta, radium, strontium-90 and tritium are regulated. However, monitoring requirements for radium and strontium-90 depend upon measured levels of gross alpha and gross beta respectively. Thus, all five parameters were examined with respect to the standard, with emphasis on gross alpha and gross beta levels for the finished water comparison.

### MICROBIOLOGICAL PARAMETERS

Of the microbiological parameters, only total coliforms are regulated in the NIPDWR. However, because of health concern, these parameters were monitored and evaluated: total coliforms, fecal coliforms, standard plate count, Salmonella, viruses, parasites, and endotoxin.

### ORGANIC PARAMETERS

Over one hundred and fifty synthetic organic chemicals (SOCs) have been routinely monitored during this project (primary compounds) and many more have been tentatively identified from mass spectra (secondary compounds). Of these, only total trihalomethanes (TTHMs), Endrin, Lindane, Methoxychlor, Toxaphene, 2,4-D and 2,4,5-TP (Silvex) are currently regulated (EPA, 1975; EPA, 1979b; EPA, 1980b). The latter six are pesticides with known chronic health effects. THMs are by-products of the water chlorination process, and chloroform is a known animal carcinogen. The other THM species are currently under investigation by EPA for carcinogenicity. Six other volatile organic chemicals (VOCs) have been proposed for regulation (EPA 1982).

EPA has evaluated numerous other SOC's for regulation and some have been assigned approximate risk levels by NAS and/or EPA with respect to potential carcinogenicity (NAS, 1977; EPA, 1979e,f,g). However, health effects for those compounds are poorly defined and little quantitative information is available. During this project as many compounds as feasible, with existing analytical technology, were monitored. An attempt has been made to identify all isolated compounds wherever possible from either standards (confirmed identification) or catalogued mass spectra (tentative identification).

## Monitoring Data Used For Evaluation

Organic monitoring results were evaluated in the following manner:

1. Two surrogate parameters, total organic carbon and total organic halides, are compared between EEWTP finished water and finished waters from the three major water suppliers.
2. The seven regulated organic parameters were compared to the MCLs and to the four finished waters. The six VOCs likely to be regulated were also compared to these finished waters.
3. Of the remaining SOC, comparisons were made between the EEWTP finished water and the other finished waters. Comparisons are made with respect to numbers of compounds identified, number of times detected, and ranges of concentrations. For compounds with higher frequency of occurrence or higher concentration in EEWTP finished water, a discussion of health significance is provided.

When available, estimated risk levels and/or alternative water quality criteria (from scientific organizations, the European Community, or other sources) are utilized to provide a context for discussion of the levels found in the EEWTP finished water.

### TOXICOLOGICAL PARAMETERS

The two toxicological parameters monitored during this project were the Ames Salmonella Mutagenicity test and the Mammalian Cell Transformation test. These tests have only recently been applied to water quality analysis and little reference data are available. Moreover, interpretation of these data is difficult. Due to the nature of the tests, little comparison can be made between results from this project and those obtained elsewhere, as discussed in Section 8 of this Chapter.

Comparisons were made between the test results in EEWTP finished water and in the finished waters from the local plants. However, it must be emphasized that the health significance, if any, of relative differences in results is not understood at this time.

### STATISTICAL PARAMETERS UTILIZED IN EVALUATING WATER QUALITY

Statistical data presented in these chapters were calculated from the monitoring program analytical results, using the techniques discussed in Chapter 5 and Appendix B. The following statistical parameters were used extensively and are briefly described here.

1. Median value. This is the central value of the sample distribution. Fifty percent of the measured samples were less than or equal to this value.
2. 90th percentile. Ninety percent of all measured values were less than or equal to this value.

## Monitoring Data Used For Evaluation

3. **Geometric Mean (G.M.).** This is the statistical parameter which describes the central tendency of the lognormal probability distribution, as discussed in Chapter 5 and Appendix B. Geometric means for this project have been calculated using a statistically rigorous algorithm which allows the reasonable estimation of geometric means at levels below the analytical detection limit.
4. **Spread Factor (S.F.).** This parameter describes the variance for the lognormal distribution, as discussed in Chapter 5 and Appendix B. For a random variable which is lognormally distributed, 68.3 percent of the data will lie between (G.M./S.F.) and (G.M.\*S.F.). The spread factor was calculated using the same iterative algorithm utilized for the geometric mean.
5. **Arithmetic Mean (A.M.).** This is the statistical parameter which describes the central tendency of the normal probability distribution, as discussed in Chapter 5 and Appendix B. Arithmetic means for this project have been calculated using assumptions that "not-detected" samples have concentrations equal to one-half of the detection limit. Unlike the geometric means, arithmetic means calculated at less than the detection limit are not reported, but are simply listed as "< D.L." Other assumptions for data detected but not quantified are as shown in Table 5.1-2 of Chapter 5.
6. **Standard Deviation (S.D.).** This parameter describes the variance of the normal distribution, as described in Chapter 5 and Appendix B. For a random variable which is normally distributed, 68.3 percent of the data will lie between (A.M.-S.D.) and (A.M.+S.D.). The standard deviation was calculated using the same assumptions as for the arithmetic mean.

## SECTION 2

### PHYSICAL/AESTHETIC PARAMETERS

#### INTRODUCTION

Several of the physical/aesthetic parameters (turbidity, total suspended solids, asbestos fibers) are related to particulate contamination of water and affect both aesthetic appeal and, potentially, consumer health. Others, such as color, MBAS, taste, and odor, are directly related to the aesthetic appeal of a finished water. These also indicate potential contamination which may or may not be of serious health concern. The remaining parameters which have been included in the "physical/aesthetic" group are general water quality indicators which have significance with respect to the operation and performance of water treatment processes. These include temperature, pH, and disinfectant residual.

#### OVERVIEW

The median values for the monitored physical/aesthetic parameters in finished water are shown in Table 9.2-1. Detailed summaries of monitoring results for all of these parameters in finished waters are shown in Table H-1 of Appendix H.

Most of the parameters in Table 9.2-1 are of special interest or concern and are considered in more detail below. These parameters are divided into two categories: 1) parameters affecting water treatment or 2) parameters of potential health and/or aesthetic concern.

#### PARAMETERS AFFECTING WATER TREATMENT

Temperature, pH, and disinfectant residual are three parameters which have direct bearing on the performance of water treatment processes. Because of potential impact on plant reliability, it is of interest to compare finished waters with respect to these three parameters. Other more specific parameters (such as turbidity, ammonia, and others) also have impacts on water treatment, but are addressed separately in later sections because of their more direct concern relative to health or aesthetics.

Table 9.2-2 shows the range of values found for pH, temperature, and chlorine residual in the EEWTP finished water during Phases IA and IB and at each of the local WTPs. Chlorine residual data from two of the local plants was not entered into the project database and was thus unavailable for this comparison.



## Physical/Aesthetic Parameters

TABLE 9.2-1  
SUMMARY OF PHYSICAL/AESTHETIC PARAMETERS  
IN FINISHED WATERS

Parameter	Units	Median Values				
		EEWTP				
		Phase IA	Phase IB	Phase IIA	WTP1	WTP2
General Parameters Affecting Water Treatment						
Temperature	deg. C	18.0	20.5	19.7	17.0	17.5
pH	pH Units	6.8	7.6	7.4	7.6	7.8
Dissolved Oxygen	mg/L	8.1	8.0	9.2	—	—
Free Chlorine	mg/L-Cl	1.6	2.5	0.1	2.1	—
Total Chlorine	mg/L-Cl	1.8	2.7	3.1	2.3	—
Parameters Also of Health and/or Aesthetic Concern						
Turbidity (grab samples)	NTU	0.10	0.10	0.05	0.32	0.20
Apparent Color	Color Units	<3	5	15	<3	8
MBAS	mg/L	0.03	0.03	<0.03	0.04	0.03
Taste	Taste Units	17	—	—	12	—
Odor	TON	17	12	4	12	8
Chrysotile Asbestos Fibers	MFL <sup>1</sup>	ND <sup>2</sup>	ND	ND	ND	ND
Amphibole Asbestos Fibers	MFL	ND	ND	ND	ND	ND

1. MFL = million fibers per liter.

2. ND = Not Detected

## Physical/Aesthetic Parameters

TABLE 9.2-2  
COMPARISON OF FINISHED WATERS  
GENERAL PHYSICAL/AESTHETIC PARAMETERS  
AFFECTING WATER TREATMENT

Parameters	Units	EWTP			
		Phase IA	Phase IB	Phase IIA	
Temperature	°C				
Range		N = 365 7.0-29.0	N = 112 9.5-26.5	N = 199 9.0-29.8	WTP1 N = 627 1.0-30.0
Arithmetic Mean/Std. Dev.		18.1/6.9	19.0/5.2	20.1/6.2	1.2-25.5
Median		18.0	20.5	19.7	15.6/7.4
pH					17.5
Range	pH Units (SMCL = 6.5 to 8.5)	N = 2158 5.3-9.2	N = 1333 5.7-8.8	N = 1079 6.9-7.8	N = 619 6.7-9.2
Arithmetic Mean/Std. Dev.		6.8/0.5	7.6/0.2	7.4/0.1	7.8/0.4
Geometric Mean/Spread Factor		6.8/1.08	7.5-1.03	7.4/1.00	7.8/1.05
Median		6.8	7.6	7.4	7.8
Free Chlorine	mg/L-Cl				
Range		N = 2438 <0.1-5.5	N = 738 0.1-6.4	N = 1150 <0.1-4.2	N = 391 1.4-3.2
Arithmetic Mean/Std. Dev.		1.6/0.64	2.42/0.67	0.20/0.42	2.11/0.25
Geometric Mean/Spread Factor		1.39/1.96	2.14/2.01	0.12/2.15	2.10/1.13
Median/90 Percentile		1.6/2.5	2.5/2.8	0.1/0.3	2.1/2.4
Total Chlorine	mg/L-Cl				
Range		N = 2434 <0.1-7.1	N = 736 1.0-11.7	N = 1195 <0.1-4.4	N = 349 1.8-3.2
Arithmetic Mean/Std. Dev.		1.98/0.65	2.83/0.77	2.98/0.42	2.31/0.28
Geometric Mean/Spread Factor		1.89/1.35	2.76/1.22	2.96/1.26	2.30/1.12
Median/90 Percentile		1.8/2.8	2.7/3.1	3.1/3.3	2.3/2.7

1. Disinfectant residual data from WTP2 and WTP3 were not monitored as part of this project. In general, WTP2 operated to a target residual of 2.5 mg/L total chlorine (all as chloramines), and WTP3 operated at a target residual of 3 mg/L total chlorine, with a free residual at 85 percent of the total.

### TEMPERATURE

Low temperatures can affect water treatment plant processes through decreasing reaction rates. As Table 9.2-2 shows, the minimum temperature observed in the EEWTP finished water during all phases was not as low as the minima which occurred in the local plants. This reflects the contribution of the treated wastewater source, which stays at an elevated temperature (relative to the local surface waters) throughout the year. Thus, the EEWTP blended influent did not reach temperatures below 6°C; estuary temperatures during the same period were, on occasion, as low as 0°C, and local plant influents reached 1°C.

The EEWTP demonstration was limited to modeling those drought situations where the estuary temperature is above 6°C. However, the conditions under which the estuary temperature would be elevated are precisely those for which EEWTP operation is being considered, namely droughts such as would occur in late spring, summer or fall. In addition, even if EEWTP influent temperatures were to drop to 1°C, changes in process efficiencies would not be substantial enough to overwhelm operational capabilities. For example, an increase in water density and viscosity in colder temperatures can affect sedimentation performance; however slightly increased doses of coagulant aid can counteract this effect. Effects on granular activated carbon and other processes are less easy to define.

In summary, however, the temperature range under which the EEWTP was operated is considered to represent adequately conditions which would occur in full-scale operation.

### pH

Control of pH has a significant impact on plant operations, particularly on the removal of certain metals via oxidation and filtration. This results from the decreased solubility (hence better removal potential), of many metals with increasing pH. As is discussed below, when alum, a pH depressant, was used, periods of low pH significantly affected results. On the other hand, the use of lime increased the pH.

Another concern related to pH, which is directly applicable to an evaluation of the finished water quality, was the potential for corrosivity in the plant finished water. This issue is discussed in a following sub-section entitled "Parameters of Concern for Health or Aesthetics".

### Alum Phase

As is described in Chapter 7, the EEWTP was operated at lower pH values than were the other local plants for the first seven months of Phase IA. This period of operation was the source of the lower minimum and lower median pH values shown in Tables 9.2-1 and 9.2-2 for the EEWTP Phase IA finished water.

In October of 1981, pH control measures were initiated at the EEWTP, and post-sedimentation lime addition was in constant operation by November of

## Physical/Aesthetic Parameters

that year. Although plant pH values dropped occasionally to below 6.5 (see Chapter 7), the period after 31 October 1981, is generally characterized by higher finished water pH. After that date, the median pH in Phase IA finished water increased to 7.1 and the number of pH values below 6.5 dropped from 31 percent for all of Phase IA to 6 percent for the period after 1 November 1981.

The change in pH control had significant impact on the EEWTP's removal of certain metals. As was addressed in Chapter 7, the issue is raised here only to emphasize the implications with respect to subsequent finished water quality discussions. Although results from the entire Phase I period are generally utilized for comparisons, it is useful, for certain parameters, to examine the EEWTP results separately from the period after pH control was initiated. In these cases, the period after 1 December 1981 is used to selectively examine the data. Although pH control was actually in use throughout November, 1 December was selected because of the use of revised sampling frequencies after that date (see Chapter 3).

### Lime Phase

During the lime phase, chemical clarification was always conducted at elevated pH, and filtration was generally conducted at pH values between 7.0 and 8.0 (see Chapter 8). pH levels in finished water did not vary widely, as in Phase IA.

As Table 9.2-2 shows, EEWTP pH values during Phase IIA operations ranged from 6.9 to 7.8 with a median, arithmetic, and geometric mean of 7.4. The indicated range is within that which occurred for both WTP 2 and WTP 3, and indicates good reliability of the lime/recarbonation system, despite some initial start-up difficulties (see Chapter 8).

### DISINFECTANT RESIDUAL

The total and free chlorine residuals in the EEWTP finished water reflect the disinfectant dose applied at the plant (with due consideration to the chlorine demand). The impact of the disinfection process on other water quality parameters is discussed in Chapter 7. These discussions provide important context for some of the results presented later in this chapter.

### Alum Phase

The lower chlorine residuals at the EEWTP, as reflected in the results shown in Table 9.2-2, are indicative of the generally lower chlorine dose applied at the EEWTP during the first three months of operation. After July 1, 1981, the target residual for free chlorine was raised from between 1.0 and 1.5 mg/L to between 2.0 and 2.5 mg/L. Influent ammonia levels, however, significantly affected the amount of chlorine required and the ability to meet the goal.

### Lime Phase

As discussed in Chapter 8, ozone was utilized as the final disinfectant during Phase IIA, in combination with 120 minutes of contact with combined chlorine

## Physical/Aesthetic Parameters

(chloramines) for the maintenance of a disinfectant residual. Chlorine residual, as shown in Table 9.2-2, averaged about 2.9 mg/L of combined chlorine. Unlike the free chlorine application of the alum phases, results were much less dependent on influent ammonia levels, because of the ability to alter the applied ammonia at the plant. However, there were periods, especially during start-up of the chlorination process, during which the appropriate chlorine to ammonia ratio was difficult to maintain. This is reflected in the wide range of chlorine residual values shown in Table 9.2-2 for the Phase IIA finished water. It should be noted, however, that over ninety percent of the observed values were between 2.5 mg/L and 3.5 mg/L.

### PARAMETERS OF CONCERN FOR HEALTH OR AESTHETICS

The parameters of health or aesthetic concern include turbidity, pH, color, MBAS (surface acting agents), odor, taste and asbestos. These are discussed below within the following contexts:

#### National Interim Primary MCL

Turbidity

#### National Secondary MCL

pH

Color

MBAS

Odor

#### Others of Potential Health and/or Aesthetic Concern

Taste

Asbestos

A brief overview of the statistics of each is given below.

Table 9.2-3 summarizes statistical information, and shows that the EEWTP finished water has median levels below those found in local finished waters for all except taste and odor. The 90th percentile value in the EEWTP finished water is less than or equal to the corresponding value in all of the monitored MWA supplies for all parameters except for odor and MBAS. For MBAS, the EEWTP 90th percentile value was less than or equal to the comparable value in two of the three local supplies.

## Physical/Aesthetic Parameters

TABLE 9.2-3  
COMPARISON OF FINISHED WATERS  
PHYSICAL/AESTHETIC PARAMETERS  
OF SPECIAL CONCERN

Parameters	Units	EEWTP			
		Phase IA	Phase IB	Phase IIA	
Turbidity (grab samples) Geometric Mean/Spread Factor Arithmetic Mean/Std. Dev. Median/90 Percentile	NTU (MCL = 1)	N = 3914 0.11/1.66 0.12/0.07 0.10/0.20	N = 668 0.10/1.46 0.11/0.05 0.10/0.15	N = 1079 0.06/1.47 0.07/0.04 0.05/0.10	WTP1 N = 554 0.33/1.94 0.41/0.32 0.32/0.76
					WTP2 N = 619 0.22/1.58 0.24/0.14 0.20/0.40
					WTP3 N = 594 0.19/0.74 0.22/0.15 0.18/0.38
Apparent Color Geometric Mean/Spread Factor Arithmetic Mean/Std. Dev. Median/90 Percentile	Color Units (MCL = 15)	N = 204 2.9/1.97 3.4/2.8 ND/7	N = 14 4.9/1.43 5.1/1.9 5/7	N = 21 10.5/1.55 11.4/4.1 15/15	N = 48 7.5/1.89 8.9/5.2 8/15
MBAS Geometric Mean/Spread Factor Arithmetic Mean/Std. Dev. Median/90 Percentile	mg/L (SMCL = 0.5)	N = 267 0.032/1.57 0.033/0.022 0.03/0.05	N = 4 0.035/1.15 0.035/0.006 0.03/0.04	N = 6 — <0.03 <0.03/0.03	N = 22 0.038/1.46 0.040/0.021 0.04/0.06
Taste <sup>2</sup> Geometric Mean/Spread Factor Arithmetic Mean/Std. Dev. Median/90 Percentile	Taste Units	N = 249 20.6/2.28 29.0/25.7 17/50	— — — —	— — — —	— — — —
Odor Geometric Mean/Spread Factor Arithmetic Mean/Std. Dev. Median/90 Percentile	TON (SMCL = 3)	N = 267 16.7/2.09 22.3/20.6 17/50	N = 23 10.4/1.58 11.5/4.9 12/17	N = 46 5.2/4.05 13.4/22.1 4/40	N = 87 9.6/2.09 12.9/12.5 8/17
Chrysotile Asbestos Fibers Avg. Conc. (Tot. Fibers/Vol. Examined) Median/90 Percentile	MFL	N = 48 0.025 ND/ND	N = 16 0.017 ND/ND	N = 24 0.011 ND/ND	N = 63 0.051 ND/0.83
Amphibole Asbestos Fibers Avg. Conc. (Tot. Fibers/Vol. Examined) Median/90 Percentile	MFL	N = 48 0.0 ND/ND	N = 16 0.0 ND/ND	N = 24 0.0 ND/ND	N = 64 0.002 ND/ND

1. N = number of samples.

2. Taste analyses terminated on 1 December 1981; not conducted at WTP2 or WTP3.

## Physical/Aesthetic Parameters

For selected physical/aesthetic parameters, Table 9.2-4 shows statistical comparisons of geometric means in the EEWTP finished water with the local finished water having the highest mean level. The table shows results of hypothesis testing utilized to demonstrate that the sampled data are, in fact, from fundamentally different underlying populations. This technique is described in Chapter 5 and Appendix B. Table 9.2-4 shows the number of degrees of freedom of the comparison and the critical t-value at the 0.05 level of significance for the one-sided test. During the alum phases of operation, odor is the only parameter for which the geometric mean in EEWTP finished water is significantly above the geometric mean in the local plants. During Phase IIA, EEWTP finished water color was significantly higher than the local plants. The significance of these results is discussed in greater detail below.

### PHYSICAL/AESTHETIC PARAMETERS WITH PRIMARY STANDARDS

Turbidity is the only physical/aesthetic parameter regulated by the NIPDWR. Turbidity is of concern with respect to aesthetics as well as potential shielding of microbiological organisms and consequent reduction in disinfection efficiency. For turbidity, the regulations require that monthly averages not exceed 1 NTU, with sampling requirements of once per day.

#### Alum Phase

The finished water at the EEWTP during Phase IA had a measured turbidity in excess of 1 NTU in only two samples out of a total of 3914 measurements in Phase IA. Using the method of frequency substitution (described in Appendix B), the 95 percent upper confidence limit on the probability of 1 NTU being exceeded is only 0.18 percent as shown in Table 9.2-5. During Phase IB of the alum operation, finished water turbidity never exceeded 1 NTU.

The two samples which exceeded 1 NTU were outliers to the generally observed lognormal distribution of the data, and are the result of extensive sampling at four hour intervals. Figure 9.2-1(a) shows a distribution of daily finished water turbidity in Phase IA using only the noon samples. From this figure, it is clear that the EEWTP had no difficulty in meeting the NIPDWR for turbidity, which requires that the monthly average of daily samples not exceed 1 NTU. Moreover, the EEWTP finished water turbidity levels were less than levels in other finished waters; see Table 9.2-4. Because of the very small probability of exceeding the NIPDWR for turbidity, combined with a favorable comparison to the local finished waters, the alum phase EEWTP finished water was considered as of acceptable quality with respect to this parameter. This was an expected result considering the multi-barrier protection against particulates which was employed at the EEWTP.

# Physical/Aesthetic Parameters

TABLE 9.2-4

APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES IN GEOMETRIC MEANS  
FOR PHYSICAL/AESTHETIC PARAMETERS IN FINISHED WATERS<sup>1</sup>

Parameter	Highest Geom Mean at Local WTP	Phase of EWTP Operation	Geom Mean At EWTP	Number of Degrees of Freedom	T	t-Statistic for 0.05 Signif. Level	Significant Difference
Turbidity	0.33	Alum-IA	0.11	555.8	-37.50	1.64	EEWTP < WTP1
		Alum-IB	0.10	557.3	-37.62	1.64	EEWTP < WTP1
		Lime-IIA	0.06	559.6	-53.86	1.64	EEWTP < WTP1
Color	7.5	Alum-IA	2.9	48.6	-9.19	1.68	EEWTP < WTP3
		Alum-IB	4.9	27.5	-3.21	1.70	EEWTP < WTP3
		Lime-IIA	10.5	34.4	2.54	1.70	WTP3 < EEWTP
MBAS	0.04	Alum-IA	0.032	259.9	-4.74	1.64	EEWTP < WTP1
		Alum-IB	0.035	3.7	-1.12	2.20	No. Signif. Diff.
		Lime-IIA 2	--	--	--	--	--
Odor	13.1	Alum-IA	16.7	100.5	2.91	1.66	WTP1 < EEWTP
		Alum-IB	10.4	39.7	-1.95	1.68	EEWTP < WTP1
		Lime-IIA	5.2	50.2	-4.24	1.67	EEWTP < WTP1

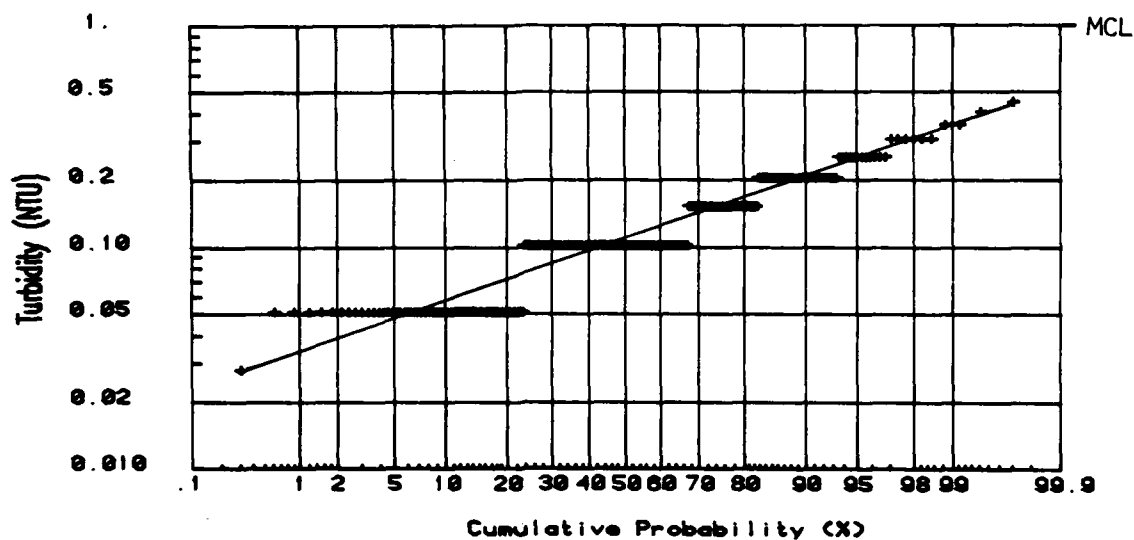
1. Hypothesis testing as described in Appendix B. One sided t-test at 0.05 significance level.
2. Insufficient quantified data for estimation of geometric mean in EEWTP finished water.



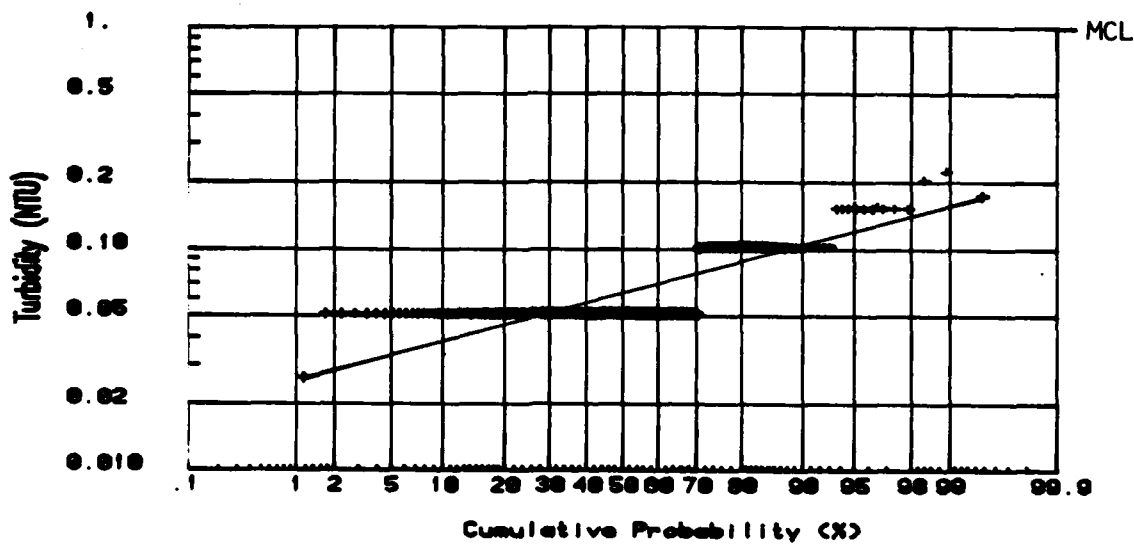
## Physical/Aesthetic Parameters

TABLE 9.2-5  
PHYSICAL/AESTHETIC PARAMETERS IN EWTP FINISHED WATERS COMPARED  
TO NIPDWR MCLS AND SECONDARY MCLS

Parameter	No. Exceeding MCL/ No. of Samples	Percent Exceeding	Upper 95% Conf. of % Exceeding	Lower 95% Conf. of % Exceeding
Turbidity; MCL = 1.0 NTU				
Alum-IA	2/3914	0.0511	0.1845	0.00619
Alum-IB	0/674	0.0	--	--
Lime-IA	0/1079	0.0	--	--
pH; SMCL = 6.5-8.5 Below 6.5:				
Alum-IA	677/2158	31.37	31.40	31.36
Alum-IB	3/1305	0.230	0.668	0.0474
Lime-IA	0/761	0.0	--	--
Above 8.5:				
Alum-IA	6/2158	0.278	0.739	0.143
Alum-IB	1/1305	0.0766	0.426	0.00194
Lime-IA	0/761	0.0	--	--
Apparent Color; SMCL = 15 Color Units				
Alum-IA	1/204	0.490	2.675	0.0124
Alum-IB	0/14	0.0	--	--
Lime-IA	0/21	0.0	--	--
MBAS; SMCL = 0.5 mg/L				
Alum-IA	0/267	0.0	--	--
Alum-IB	0/4	0.0	--	--
Lime-IA	0/6	0.0	--	--
Odor; SMCL = 3.0 TON				
Alum-IA	265/267	99.25	99.91	97.34
Alum-IB	22/23	95.65	99.89	77.98
Lime-IA	27/46	58.70	73.06	43.27



(a) Turbidity Results for Noon Grab Samples in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA)



(b) Turbidity Results from Noon Grab Samples in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA)

**TURBIDITY RESULTS IN EEWTP FINISHED WATER  
(PHASE IA AND PHASE IIA)  
FIGURE 9. 2-1**

## Physical/Aesthetic Parameters

### Lime Phase

As indicated in Tables 9.2-4 and 9.2-5, the EEWTP finished water during the lime phase never exceeded the NIPDWR for turbidity and compares favorably with all monitored MWA supplies. The distribution of daily (noon) grab sample results is shown in Figure 9.2-1(b). As is evident from the plot, finished water quality during the lime mode of operation was of excellent quality with respect to turbidity.

### PHYSICAL/AESTHETIC PARAMETERS WITH SECONDARY STANDARDS

The physical/aesthetic parameters for which secondary MCLs exist include pH, color, MBAS (foaming agents), and odor. Table 9.2-5 shows the frequency with which the secondary standards were exceeded in the EEWTP finished waters. Estimates of the 95 percent confidence bounds around these frequencies are also shown.

### pH

The secondary regulations for pH specify a recommended range of 6.5 - 8.5. The primary purpose of a minimum pH standard is the concern for corrosion potential (EPA, 1979a), with associated economic impacts and health implications related to dissolution of lead, cadmium, and other corrosion by-products in distribution systems. It is well recognized, however, that corrosivity is dependent on many interrelated factors and not tied to pH alone. The secondary regulations state separately that drinking water should be "non-corrosive", with corrosivity "determined on a case-by-case basis through the exercise of judgement by the States" (EPA, 1979a). No specific MCL for corrosivity was established because no single universal index was available which was considered applicable to all situations.

High pH levels in finished waters are considered undesirable because of several potential indirect concerns. One such concern is that high pH levels may impart a bitter taste to the water. High pH levels also depress the effectiveness of disinfection by chlorination and have been shown to accelerate the production of trihalomethanes due to chlorination. In addition, the greater driving force for mineral precipitation associated with alkaline waters may result in pipe encrustation (EPA, 1979a).

Within the context of these concerns, an evaluation of finished water corrosivity was conducted as part of the engineering studies on this project (Chapter 10), and a discussion of plant pH control and corrosivity has been provided separately in Chapter 7. With respect to meeting the secondary MCLs, the specific pH values obtained during the alum and lime phases are discussed separately below.

Alum Phase. The EEWTP finished water pH was below a level of 6.5 in 680 measurements out of a total of 3,491 during the two alum phases of operation. However, pH levels were significantly lower during the period prior to October 1981 when pH control measures were put into effect. Ninety-one percent of

## Physical/Aesthetic Parameters

the values less than 6.5 occurred prior to 1 November 1981. Between 1 November 1981 and 16 March 1982 (the remainder of Phase IA) only 59 of 948 (6 percent) of finished water pH measurements were below 6.5. These were predominantly during periods of high influent ammonia and correspondingly high chlorine dosages, as discussed in Chapter 7. During Phase IB, the finished water pH reached levels below 6.5 in only three of 1,345 measurements (0.2 percent), indicating that there were few problems with pH control during this period.

These results indicate that low pH is a potential concern with respect to the EEWTP alum treated water, but that it is one one which can be fully controlled by appropriate operational measures.

The upper limit of the pH secondary MCL was exceeded six times during the twelve month, Phase IA period. These six values represent 0.28 percent of the 2,158 pH samples taken. With respect to chlorination efficiency or taste, these very few high values would not be discernible.

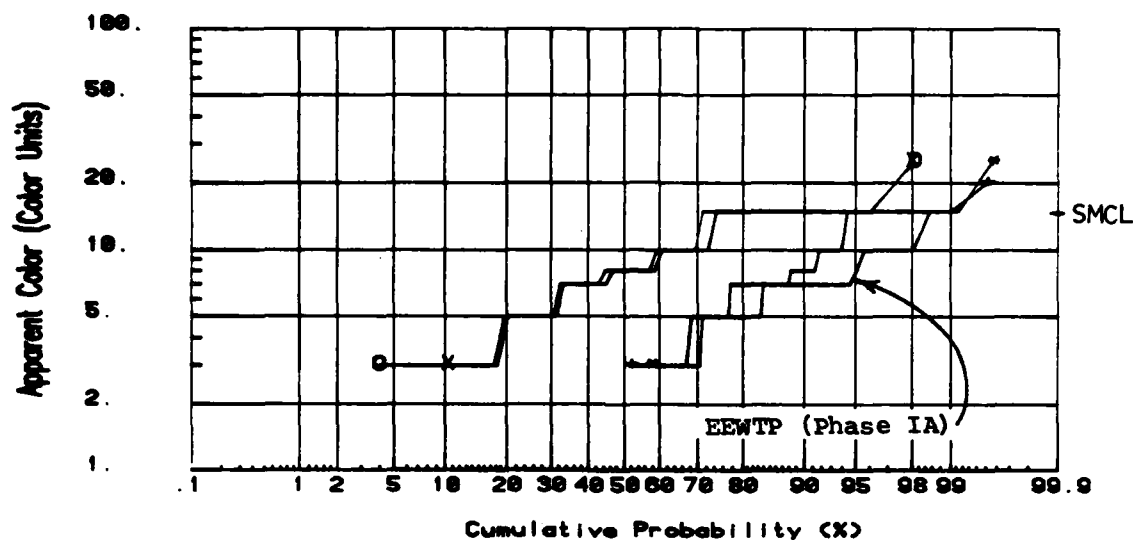
Lime Phase. The EEWTP finished water pH during Phase IIA was always within the EPA Secondary regulation range. As shown in Table 9.2-2, the EEWTP pH range was also narrower than for two of the local MWA plants. These results show acceptable pH control during EEWTP operation with lime.

### Color

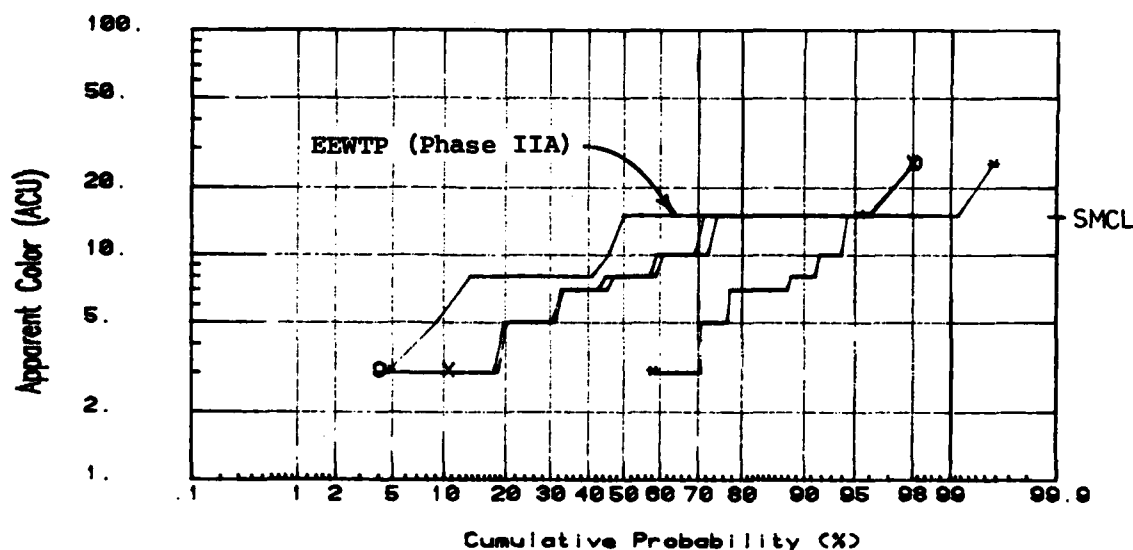
The EPA has set a secondary MCL for color of 15 color units, primarily for aesthetic reasons, as highly colored water may discourage consumers. Colored water can also indicate the presence of humic and fulvic materials in the water. These have been shown to comprise precursor material in the trihalomethane formation reaction.

Alum Phase. As indicated in Table 9.2-5, the color level in the alum phase EEWTP treated water samples never exceeded the secondary standard of 15 color units. The large majority of the samples were well below the standard with over fifty percent having no detectable apparent color. Moreover, the 90th percentile value in the EEWTP finished water was less than the equivalent percentile in all three local finished waters, as shown in Table 9.2-3 and Figure 9.2-2(a). Hypothesis testing demonstrates that the geometric mean color in the alum phase finished water was significantly less than in the highest local plant, with over 95 percent probability that this conclusion is not in error. Color is thus not a factor of concern for the alum phase finished water quality.

Lime Phase. During Phase IIA operations, none of the samples exceeded the secondary MCL of 15 color units, although fifty percent of the samples were equal to it. As Figure 9.2-2(b) illustrates, two of the local plants exceeded the SMCL, although very infrequently. The local plants exceeded the SMCL, at worst, only four percent of the time (Figure 9.2-3). Most frequently, the other finished waters showed lower finished water color; the medians and geometric means for all three are less than the corresponding values for the EEWTP Phase IIA finished water.



(a) Color Results in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Color Results in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**COLOR RESULTS IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 2-2**

## Physical/Aesthetic Parameters

The lack of intermediate oxidant, and the changeover from chlorine to ozone and chloramines for final disinfection were cited above as a potential reason for this poorer performance for color removal during Phase IIA operations. This comment can be quantified by considering the mean color removal efficiencies between the influents and filter effluents, and between the filter effluents and finished waters for the different phases of EEWTP operations. As Table 9.2-6 illustrates, cumulative percent color removal during Phases IA and IB was better than during Phase IIA.

TABLE 9.2-6  
COLOR REMOVAL WITHIN EEWTP DURING  
PHASES I AND IIA

	Units	EEWTP Influent	Filter Effluent	Finished Water
EEWTP Phase IA Color <sup>1</sup>	Color Units	33.7	4.4	2.9
Cumulative Percent Removal	%	—	87	91
EEWTP Phase IB Color	Color Units	44.9	8.2	4.9
Cumulative Percent Removal	%	—	82	89
EEWTP Phase IIA Color	Color Units	47.3	12.2	10.5
Cumulative Percent Removal	%	—	74	78

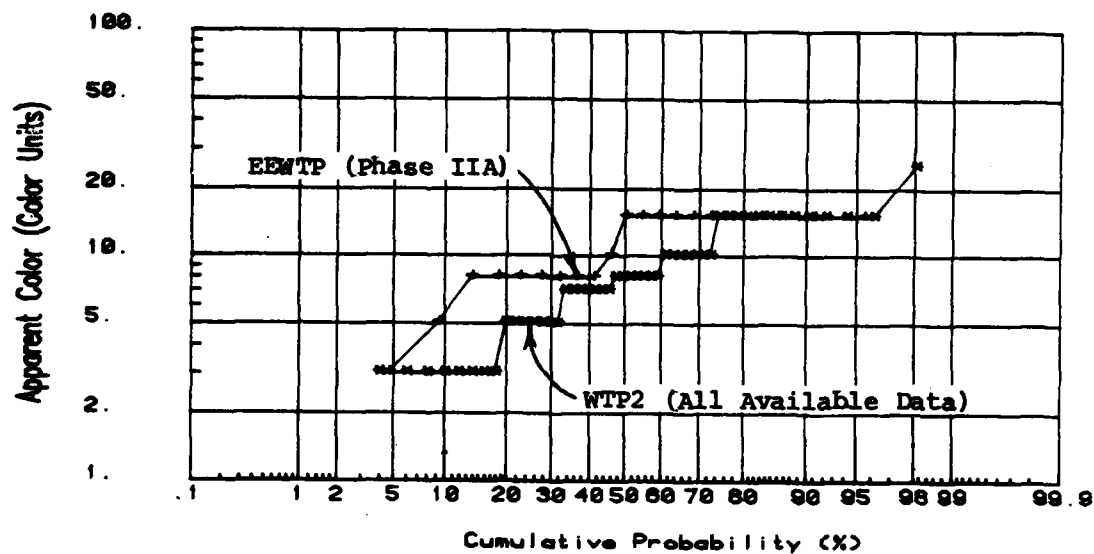
1. Using geometric mean value.

It is clear that the EEWTP process train can be designed to achieve the desired effluent color level; however, other constraints on the use of intermediate oxidants and the choice of final disinfectant may make color removal a low priority constraint. This may be particularly true in as much as the Phase IIA finished water, although less acceptable (in terms of color) than Phase IA finished water, did in fact always meet the SMCL.

### MBAS

The SMCL of 0.5 mg/L MBAS was established to limit the concentrations of anionic surfactants which can cause undesirable tastes and foaming in water. Concentrations above this limit may result from contamination of raw water sources with detergents.

As indicated in Table 9.2-3, the median values during all phases are less than or equal to those in the local plants. The 90th percentile value also compares favorably with all of the three local plants. MBAS levels in the EEWTP finished water never exceeded the secondary standard for foaming agents of 0.5



**COLOR RESULTS IN FINISHED WATER  
COMPARED TO RESULTS FROM WTP2  
(PHASE IIA)  
FIGURE 9. 2-3**

## Physical/Aesthetic Parameters

mg/L. At the levels of MBAS observed in the EEWTP finished water, there is no potential for foaming, taste, or other potential aesthetic effects, and this parameter is not one of concern.

### Odor

Pure water does not produce odor sensations. However, most organics and some inorganic chemicals do stimulate human olfactory receptor cells, and, if present in sufficient concentration, will cause a water to have a perceived odor. Such chemicals may originate from municipal and industrial waste discharges, from water treatment processes (such as chlorination), from natural sources, or from associated microbial activity. The EPA has recognized the importance of odor with respect to the aesthetic appeal of drinking water, and has established a secondary MCL at a threshold odor number of 3 TON. Because of consumer acceptance issues, odor is an especially important concern for drinking waters which come from contaminated sources.

Threshold odor numbers (TON) in water samples reflect the number of dilutions which are required before no further odor is detected (Standard Methods, 1980). Table 9.2-7 shows the threshold odor numbers which correspond to various dilutions of sample water, when diluted with odor-free water. The test is quite subjective and results will vary with the sensitivity of the odor panel reviewing the samples. Individuals vary in response to the characteristic, as well as the concentration of the odorant. Moreover, a given individual's sensitivity will vary over time, with both day-to-day and within-day differences occurring.

TABLE 9.2-7

### THRESHOLD ODOR NUMBERS CORRESPONDING TO VARIOUS DILUTIONS

<u>Sample Volume</u> <u>Diluted to 200 ml</u> <u>ml</u>	<u>Threshold</u> <u>Odor No.</u>	<u>Sample Volume</u> <u>Diluted to 200 ml</u> <u>ml</u>	<u>Threshold</u> <u>Odor No.</u>
200	1	12	17
140	1.4	8.3	24
100	2	5.7	35
70	3	4	50
50	4	2.8	70
35	6	2	100
25	8	1.4	140
17	12	1.0	200

In general, the odor results observed during this project have been quite high, both in the EEWTP finished water and the local MWA supplies. Table 9.2-5 shows the frequency with which the secondary MCL was exceeded in the



## Physical/Aesthetic Parameters

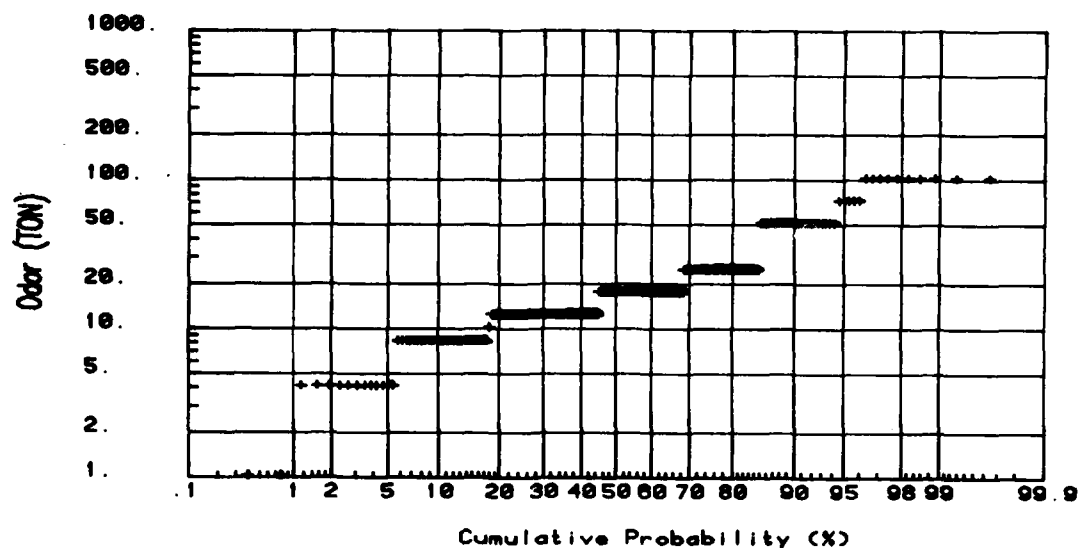
EEWTP. Multiple measurements in excess of 15 TON are generally indicative of highly odorous water. On-site EEWTP personnel, however, did not have this perception for any of the waters; moreover, odor panel analyses at the local WTPs did not show similarly high results on those waters. These circumstances seemed to indicate that the odor results from this project were unusually high, either due to a high degree of sensitivity in the odor panel or due to effects related to storage and shipment of the samples. A comparative odor study was conducted between the project's off-site panel and the panel at one of the local plants. The results of this comparative study, which are provided in Appendix A, indicate that the project panel was, in fact, much more sensitive to chlorinous type odors.

The standard testing method for odor requires that all test conditions be standardized when comparisons are made between odor data taken at different times and/or places (Standard Methods, 1980). This consideration, together with the demonstrated high sensitivity of the project odor panel, lead to a conclusion that project odor results should not be evaluated relative to "typical" results or to the EPA SMCL. Because odor results from the local plants were obtained in a similar manner to those from the EEWTP, comparison of the finished waters is the most appropriate means for evaluating finished water quality with respect to this parameter. Such a comparison is provided for finished water from each of the EEWTP phases in the following sections.

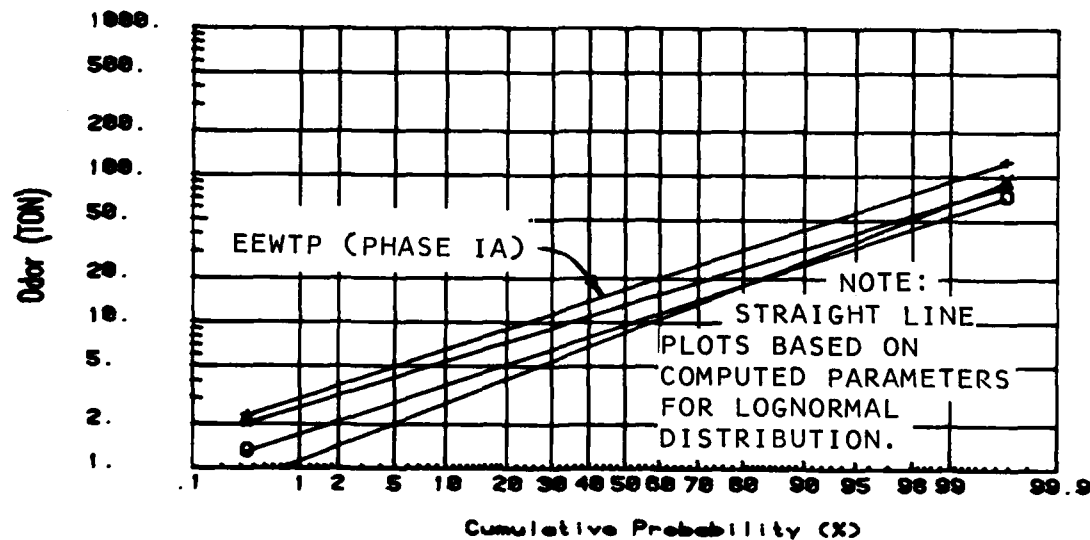
Alum Phase. As indicated in Tables 9.2-3 and 9.2-5, a statistical analysis of threshold odor numbers (TON) in the EEWTP finished water during Phase IA compares unfavorably to all of the monitored MWA supplies. The probability distribution of odor results in the Phase IA finished water is shown in Figure 9.2-4(a). The distributions from all four finished waters are shown in Figure 9.2-4(b), as modeled by straight lines constructed from calculated geometric means and spread factors.

In reviewing the results shown in Figure 9.2-4, it is important to realize that EEWTP finished water odor sampling was begun on 16 March 1981, whereas local plant sampling did not begin until 1 December 1981. Because of the variability of the odor test, as previously discussed, and because of potential effects due to finished water temperature, it is more meaningful to look at the EEWTP and MWA plant data which were collected over the same period of time. Figure 9.2-5(a) shows threshold odor numbers from the EEWTP and WTP1 finished waters, with all data taken from samples collected between 1 December 1981 and 16 March 1982. During this period, the distributions of odor data at the two sites are almost indistinguishable, although the EEWTP finished water did have two values at the high end of the distribution which were above all WTP1 values. A comparison of geometric means from these two populations indicates no difference at the 0.05 significance level.

Finished water odor levels during Phase IB are shown in Figure 9.2-5(b), along with the data from WTP1, the local plant with the highest odor levels, collected over the same time period. The odor levels in EEWTP finished water during this phase were less than or equal to the levels in WTP1 finished water at all percentiles. As was true for the Phase IA finished water and WTP1, a



(a) Odor results in EEWTP finished water  
(16 March 1981 to 16 March 1982 - Phase IA)



(b) Odor results in EEWTP finished water (Phase IA)  
and at three local WTPs (all available data)

**ODOR RESULTS IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
(PHASE IA)  
FIGURE 9. 2-4**

## Physical/Aesthetic Parameters

comparison of the geometric means of the odor values from Phase IIA finished water and WTP1 during the same time period show no significant difference.

Although the odor levels in EEWTP finished water have been demonstrated to be roughly comparable to those observed in local MWA supplies, the occasional deviations during Phase IA indicate a potential problem with respect to the aesthetic appeal of the water at certain times.

Most odors are too complex and are detectable at concentrations too low to permit their definition by isolating and determining the odor-producing chemicals. Extensive organic monitoring (discussed later in this chapter) provided little insight as to the source of the high odor results in the finished waters.

The only remaining indication of the nature of the odors lies in a review of the qualitative remarks made by the odor panelists. Tables 9.2-8 and 9.2-9 show the nature of the comments which were recorded for some of the alum phase finished water samples. Although panelists did not record comments for all samples, those shown do indicate the general nature of the odors. The predominant comment recorded was "chlorinous" or "chlorine". All of the very high odor numbers (50 or greater) in EEWTP finished water were either uncommented or carried this remark. However, it must be noted that the large majority of the high values occurred between 1 May 1981 and 1 January 1982, when comments were not recorded by panelists.

Due to the nature of the analysis and the similarity of finished water results, it is impossible to determine if odor in the alum phase finished waters would, in fact, pose potential consumer acceptance problems. Considering the nature of the proposed source, it is likely that consumers would be especially demanding with respect to taste and odor. Any comparison to local supplies which is other than favorable would indicate potential for serious concern. Proper pH control and the application of intermediate ozonation during Phase IB did appear to bring odor levels below those in the local plants. Finished water geometric means at the EEWTP and WTP 1 were not statistically different (at the 0.05 significance level), when data from equivalent time periods were used.

On the basis of the available data, the alum process train is considered to have been an acceptable process combination with respect to odor, although close control of pH adjustment and chlorine addition are required.

**Lime Phase.** Table 9.2-3 indicates substantial reduction in the median TON value obtained during Phase IIA as compared to either alum phase. As is shown in Figure 9.2-6, at all percentiles less than or equal to the 50th, the values obtained at the EEWTP during Phase IIA were substantially lower than any of the local plants. In comparing the local plant with highest values to Phase IIA operations (Figure 9.2-7), it can be seen that the EEWTP performed better up to the 70th percentile. In fact, the values are less than or equal to the SMCL seventy percent of the time during the lime phase operations.

Physical/Aesthetic Parameters

TABLE 9.2-8  
PHASE IA - ODOR RESULTS  
16 MARCH 1981 - 16 MARCH 1982

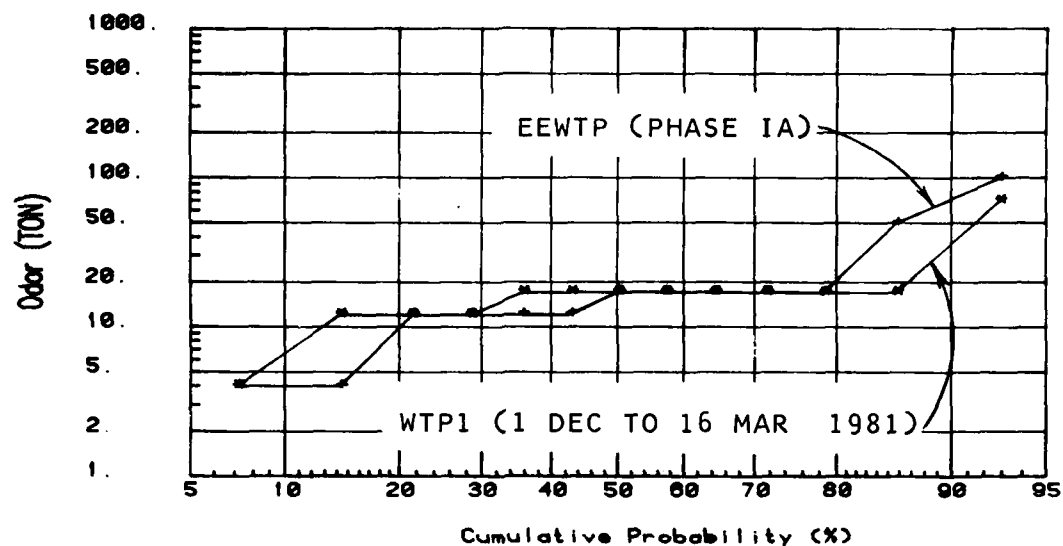
	EEWTP		WTP1 <sup>2</sup>	WTP2 <sup>2</sup>	WTP3 <sup>2</sup>
	<u>GAC</u> <u>Effluent<sup>2</sup></u>	<u>Finished</u> <u>Water</u>			
No. of Samples	10	267	14	8	12
Median Value	12	17	17	12	12
90% Less Than	17	50	17	50	17
No. of Samples With Comments <sup>1</sup>	5	15	7	4	5
Distribution of Comments:					
Chlorine Odor	2	12	6	2	4
Slight Chlorine Odor		1			
Musty, Chlorine Odor		2			
Sweet Earthy Odor	1			1	
Dirty	2		1	1	1
Insufficient Sample For Further Dilution		1			

1. Note: comments not recorded between 1 May 1981 and 1 January 1982.

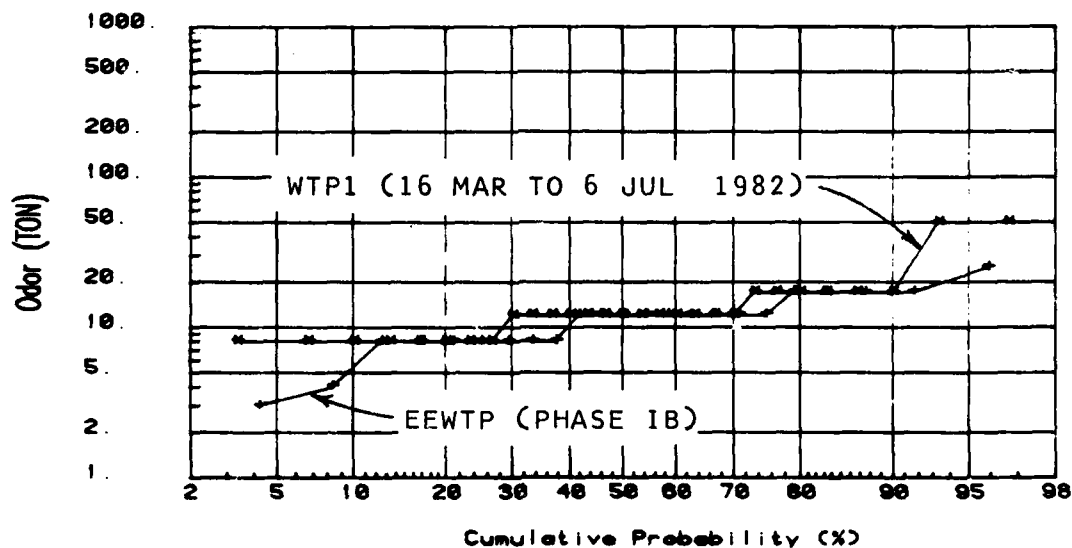
2. Sampling initiated on 1 December 1981.

TABLE 9.2-9  
PHASE IB - ODOR RESULTS  
17 MARCH 1982 - 6 JULY 1982

	EEWTP		WTP1	WTP2	WTP3
	<u>GAC</u> <u>Effluent</u>	<u>Finished</u> <u>Water</u>			
No. of Samples	23	23	29	25	23
Median Value	3	12	12	8	8
90% Less Than	17	17	17	12	17
No. of Samples With Comments	19	28	29	25	23
Distribution of Comments:					
Chlorine Odor	5	12	11	9	6
Slight Chlorine Odor	3	2	1	1	4
Musty, Chlorine Odor	3	14	6	8	7
Very Musty, Slight Chlorine	3	1		2	2
Musty Odor	3	3	5	5	4
Dirty		2	3		3
Sweet	3			1	1
Other					
1) Pond			1		
2) Food-Burrito, Hot Dog				1	
3) Hand Lotion	1				
4) Slight Decaying Matter	1				



(a) Odor results from equivalent monitoring period  
(1 December 1981 to 16 March 1982 - Phase IA),  
EEWTP and WTP1 finished waters



(b) Odor results from equivalent monitoring period  
(16 March 1982 to 6 July 1982 - Phase IB),  
EEWTP and WTP1 finished waters

**ODOR RESULTS IN EEWTP FINISHED WATER  
COMPARED TO RESULTS FROM WTP1  
(PHASES IA AND IB)  
FIGURE 9. 2-5**

## Physical/Aesthetic Parameters

Odor comments from the lime phase are presented in Table 9.2-10. Again, chlorine was the predominant odor at all local sites. Despite the revised disinfection process at the EEWTP, this comment continues to appear for the EEWTP finished water. The only other comments recorded more than once in EEWTP finished water were "dirty", "sweet", and "musty". Each of these comments were made on local supplies even more often during the same time period.

Because the water compares favorably to the local supply, the process is considered to have been of acceptable quality. The high TON values observed are considered to be related to the specific analysis as conducted and not comparable to results external to this project.

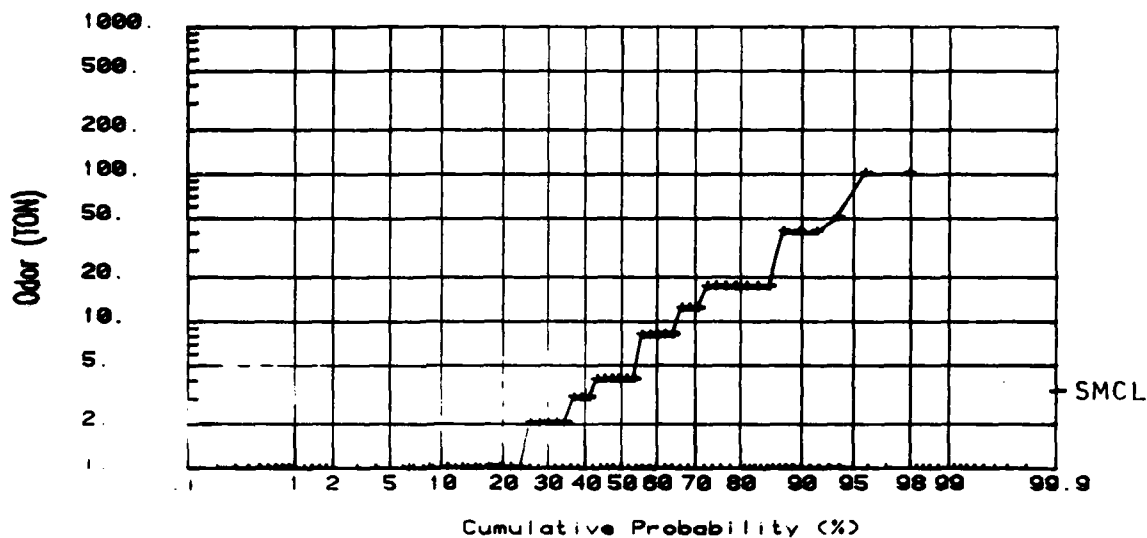
### OTHER PHYSICAL/AESTHETIC PARAMETERS OF CONCERN

#### Taste

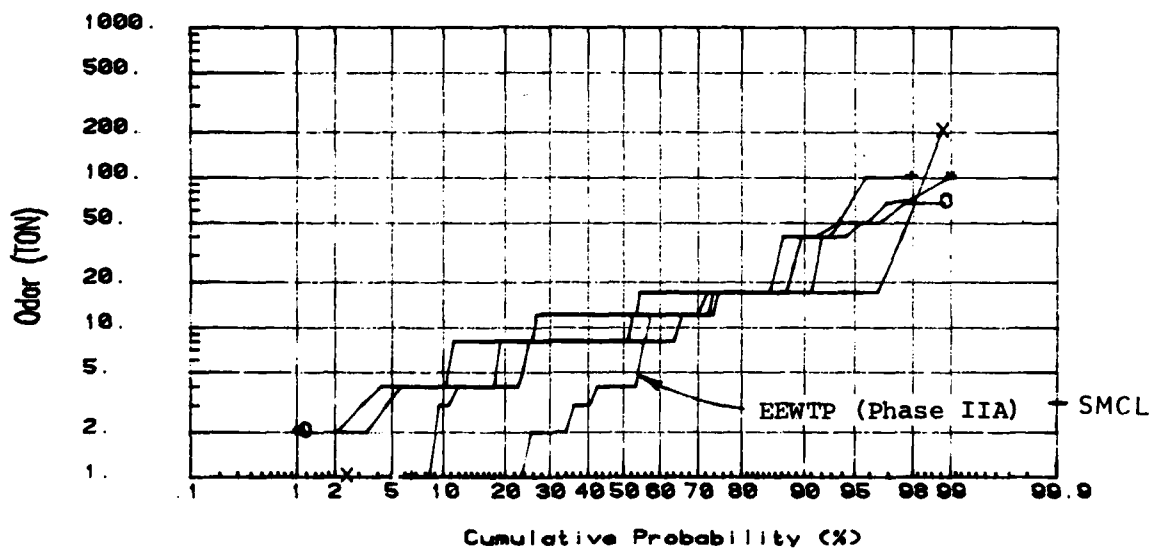
Many taste producing substances are beneficial in proper concentrations and it should not be assumed that a tasteless water is most desirable. Some substances, such as certain inorganic salts, produce taste without odor, and are perceived by taste buds, primarily on the tongue. Many other sensations ascribed to taste are odors, and are perceived not on the tongue, but high in the nasal cavity. The actual sensation experienced during the act of tasting is actually a combination of taste, odor, temperature, and feel.

The taste threshold test is utilized to measure taste intensity. This test was utilized during the first nine months of the project on both EEWTP Phase IA finished water and finished water from WTP1. Because results were fairly similar between the taste and odor tests in EEWTP finished water, it is likely that odor sensations had a large impact on the results. Other factors may have also had an effect, however, and are difficult to interpret. It was for this reason that the taste test was discontinued on 1 December 1981, and odor testing begun at all finished water sites.

The taste threshold tests from Phase IA are useful in that they do provide some data for comparison in the period prior to 1 December when comparative odor testing was begun. It appears, from Table 9.2-3, that the EEWTP finished water did have a moderately higher taste threshold than WTP1 during this period. Although varying levels of inorganic salts may be affecting these results, the results tend to substantiate previous concern for potential taste and odor problem during Phase IA.

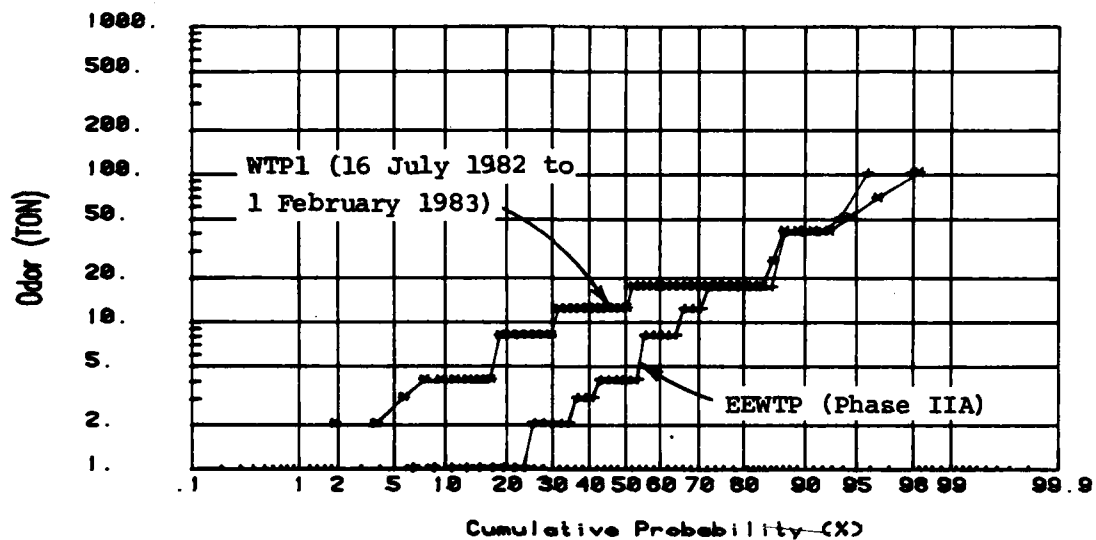


(a) Odor Results in EEWTP Finished Water (16 July 1982 to February 1983 - Phase IIA)



(b) Odor Results in EEWTP Finished Water (Phase IIA) and at Three Local Plants (All Available Data)

**ODOR RESULTS IN EEWTP  
AND AT THREE LOCAL WTPs  
(PHASE IIA)  
FIGURE 9. 2-6**



**ODOR RESULTS IN EEWTP FINISHED WATER  
COMPARED TO RESULTS FROM WTP1  
(16 JULY 1982 TO 1 FEBRUARY 1983)  
(PHASE IIA)  
FIGURE 9. 2-7**



# Physical/Aesthetic Parameters

TABLE 9.2-10

PHASE IIA  
ODOR RESULTS  
16 JULY 1982 - 1 FEBRUARY 1983

	EEWTP		WTP1	WTP2	WTP3
	GAC Effluent	Finished Water			
No. of Samples	47	46	53	54	48
Median Value	2	4	12	8	8
90% Less Than	17	40	40	40	17
No. of Samples With Comments	28	29	47	45	34
Distribution of Comments:					
Chlorine	2	12	19	8	14
Musty, Chlorine Odor		2	16	7	4
Musty Odor	6	5	4	17	11
Earthy	2		2	1	1
Sweet Earthy Odor		1		2	1
Sweet	4	6	7	5	11
Musty, Sulfur Odor	1		1		
Dirty	6	5	9	13	8
Other					
1. Fishy	6	1			1
2. Grassy	2		1	1	1
3. Sewage	3		2		
4. Trash/Garbage	2				
5. Moldy	3		1		
6. Cat Urine	1				
7. Sulfur	2	1	1		
8. Rusty Smell	1				1
9. Soil		1	1	1	
10. Dusty		1			
11. Petroleum		1			
12. Soapy		1			
13. Broccoli		1			
14. Rotten Food		1			
15. Plastic			1		
16. Pears					1
17. Carrots				1	
18. Organic					1

### Asbestos

Numerous epidemiological studies have shown that exposure to asbestos dust in air can lead to asbestosis (characterized primarily by pulmonary fibrosis) or other pulmonary and bronchial diseases. Gastronintestinal effects from the ingestion of fibers are still under investigation (NAS, 1977).

The net concentrations of asbestos fibers in monitored waters were determined by dividing the total number of fibers observed by the equivalent volume of water examined under the electron microscope. The 'equivalent' volume is based on the volume of water filtered and the percent of filter grid area examined. Raw data and fiber distributions are provided in Appendix H, with summary information as presented in Table 9.2-3 of this chapter.

The concentrations of chrysotile fibers observed in EEWTP finished waters are well below those observed in the local supplies, with average concentrations between five and ten times less than the average concentration in the highest local finished water. The latter was still well below a million fibers per liter and in the range of minimum background concentrations found in regions remote from industrial and populated areas (NAS, 1977).

Over ninety percent of all EEWTP finished water samples had non-detectable levels of chrysotile fibers. Amphibole fibers were not detected in any EEWTP finished water sample. On the basis of these findings, asbestos fibers do not represent any concern with respect to the relative acceptability of the EEWTP finished water.

### SUMMARY

#### Alum Phase

Alum phase finished water compared favorably to the three major MWA supplies with respect to all physical/aesthetic parameters of concern except for pH, odor, and taste.

pH is a parameter which is readily controlled through plant operating procedures and is discussed at length in Chapters 7 and 10 of this report. The lower pH of the EEWTP finished water was primarily the result of (1) an initial period of operation with no pH control and (2) occasional periods of high chlorine dose during the times of high influent ammonia. Extended periods of low finished water pH are avoidable through careful plant design and operation, as discussed in Chapter 7, and this parameter is not one of major concern.

With respect to taste and odor, odor was the parameter of most concern, and for which analysis continued during all phases of operation and at all local supplies. The odor results during Phase IA indicated some periods of high odor in excess of that observed at local plants. During comparable time frames, however, the results were much more similar, although the two highest EEWTP TON values did exceed those observed at the local plants. During Phase IB, with intermediate ozonation, EEWTP finished water results had lower threshold

## Physical/Aesthetic Parameters

odor numbers than the local supplies at all percentiles. In general, the EEWTP finished water during the alum phase was considered to be of acceptable quality with respect to this parameter, with recognition that careful attention to the disinfection process is critical toward avoiding potential problems, as discussed in Chapter 7.

Alum phase results compared favorably to all federal MCLs and SMCLs for physical/aesthetic parameters, with the exception of odor. Because of the extreme subjectivity of this test and the demonstrated sensitivity of the project odor panel, comparison to external results or standards is not appropriate for this parameter; comparison to the local supply was most critical, as discussed above.

### Lime Phase

Lime phase finished waters compared favorably to the local supply with respect to all physical/aesthetic parameters except for color. In the case of color, the EEWTP finished water, while significantly above the highest local supply, did not exceed the federal secondary MCL of fifteen color units. It should be noted, however, that fifty percent of the samples were at the SMCL. The levels of color present in EEWTP finished waters are not considered to be sufficiently high to warrant concern with respect to the feasibility of the supply for drinking water. If desired, plant oxidation process strategy could be modified to decrease the color levels in finished water.

As with the alum phase, odor was the only parameter exceeding the federal secondary standard. Again, comparison with the standard is inappropriate in light of the nature of the test. Internal project results showed favorable comparison to all locally monitored supplies.

## SECTION 3

### MAJOR CATIONS, ANIONS, AND NUTRIENTS

#### INTRODUCTION

The category of major cations, anions, and nutrients includes a number of mineral species which are universally found in drinking waters at various levels. Many of these parameters are essential in human nutrition. Others are unimportant to human health and have no effect at concentrations typically found in natural waters. For most of these mineral species, no toxic effects can be observed except at extremely high concentrations. Instead, very high levels result in salty tastes which can be objectionable to consumers. Certain mineral species, such as nitrate, have significant toxic health effects above a given level. For others, the epidemiological literature on health effects is ambiguous.

The basis for evaluating the quality of EEWTP finished water with respect to mineral species has been to examine each parameter measured, beginning with minerals which are regulated by primary and secondary drinking water standards. For those species, comparison to the standard gives an indication of the acceptability of the finished water. For other mineral parameters, the concentrations observed in EEWTP finished water are compared to those in local finished waters in the Metropolitan Washington Area. Specific minerals with known health effects are investigated in detail.

#### OVERVIEW

Median concentrations of major cations, anions, and nutrients for the EEWTP finished water samples taken during Phase IA, and for local finished water samples taken over the entire study period, are summarized in Table 9.3-1. Because the raw water entering the EEWTP consists of a blend of Potomac estuary water and treated wastewater, the median levels of most minerals in EEWTP finished water are higher than those in local plants for which raw waters are typical surface waters. Higher EEWTP concentrations result primarily from the treated wastewater source which contains increments in mineral concentrations added during domestic use. For some of the less common species such as bromide, cyanide, and orthophosphate, the median concentrations observed are below the method detection limits.

Individual water quality parameters which are of concern for health or aesthetic value are discussed separately below. These include those parameters for which federal regulations have been promulgated, as well as other mineral species of significance for which the EEWTP finished water has higher concentrations than all finished supplies from local plants.

## Major Cations, Anions, and Nutrients

TABLE 9.3-1  
SUMMARY OF MAJOR CATIONS, ANIONS, AND NUTRIENTS  
IN FINISHED WATERS

Parameter	Units	Median Values					
		EEWTP				WTP3	
		Phase IA	Phase IB	Phase IIA	WTP1		WTP2
Total Dissolved Solids (by addition)	mg/L	293	246	303	188	123	168
Electroconductivity	µmho/cm	470.0	460.0	580.0	335	230	330
Major Cations							
Calcium	mg/L	47.1	51.7	65.9	42.3	25.0	40.1
Hardness	mg/L-CaCO <sub>3</sub>	153	156	190	138	80	133
Magnesium	mg/L	7.9	6.8	5.4	7.5	4.4	7.4
Potassium	mg/L	6.1	5.0	6.3	2.6	2.9	2.7
Sodium	mg/L	29.8	24.9	33.3	11.4	11.9	11.3
Anions							
Alkalinity	mg/L-CaCO <sub>3</sub>	37.6	61.0	96.0	80.0	41.6	67.0
Bromide	mg/L	<0.003	<0.003	0.031	<0.003	<0.003	<0.003
Chloride	mg/L	48.0	47.0	63.0	20.0	20.0	36.0
Cyanide	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fluoride	mg/L	0.3	0.3	0.5	0.9	0.9	0.9
Iodide	mg/L	0.003	—	—	0.003	0.002	—
Silica	mg/L	5.7	6.0	4.7	4.3	7.5	4.6
Sulfate	mg/L	90.0	62.0	55.4	47.1	30.0	30.0
Nutrients							
Nitrogen: Nitrate + Nitrite	mg/L-N	7.6	6.9	8.3	1.4	0.9	1.6
Nitrogen: Ammonia	mg/L-N	<0.02	<0.02	0.80	<0.02	0.45	<0.02
Nitrogen: Total Kjeldahl	mg/L-N	0.3	<0.2	1.0	0.3	0.7	0.3
Orthophosphate	mg/L-P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

## PARAMETERS OF CONCERN FOR HEALTH OR AESTHETICS

Major cations, anions, and nutrients of health or aesthetic concern are discussed below within the following categories:

### National Interim Primary MCL

Fluoride

Nitrate

Sodium (no MCL, but included in Primary Regulations, monitoring required)

### Secondary MCL

Total Dissolved Solids

Chloride

Sulfate

### Others Not Regulated of Health or Aesthetic Concern

Ammonia

Cyanide

Bromide

Hardness, Calcium and Magnesium

Statistical information for each of these parameters is summarized in Table 9.3-2, for EEWTP finished water during all phases of operation and for local finished waters during the two years of monitoring. This includes geometric means, arithmetic means, medians and 90th percentile values.

Table 9.3-3 shows the results of hypothesis tests comparing geometric mean concentrations in EEWTP finished water during Phase IA and the concentration in the local finished water with highest levels of each parameter. This comparison shows whether the EEWTP finished water had higher geometric mean values than the highest WTP, with the means demonstrated not to be the same at the 0.05 significance level.

Because of the increased mineralization in the Potomac estuary or in the treated wastewater, the EEWTP finished water during all phases had significantly higher concentrations of total dissolved solids (TDS), sodium, nitrate plus nitrite, hardness and sulfate than in all local plants. The geometric mean for chloride was significantly higher than the highest local supply during two of the three EEWTP phases, and bromide was higher in one. The significance of these higher concentrations is discussed in greater detail below.

## MAJOR CATIONS, ANIONS, AND NUTRIENTS WITH PRIMARY STANDARDS

Minerals for which a federal drinking water primary or secondary standard have been promulgated (fluoride, nitrate, TDS, chloride, and sulfate) are listed in Table 9.3-4. For each parameter the frequency with which the standard was exceeded in the EEWTP finished water is shown. Of these, fluoride and nitrate are the only two parameters with primary standards.

## Major Cations, Anions, and Nutrients

TABLE 9.3-2

COMPARISON OF FINISHED WATERS  
MAJOR CATIONS, ANIONS, AND NUTRIENTS  
OF CONCERN FOR HEALTH OR AESTHETICS

Parameter	Units	EWTP				WTP1	WTP2	WTP3
		Phase IA	Phase IB	Phase II A	Phase II B			
Total Dissolved Solids (by addition)								
Geometric Mean/Spread Factor	mg/L	N = 271	N = 28	N = 53		N = 103	N = 102	N = 96
Arithmetic Mean/Standard Deviation	(SMCL=500)	299/1.12	231/1.22	302/1.14		182/1.23	128/1.16	172/1.21
Median/90 Percentile		301/35	235/40	304/43		186/39	129/21	175/35
		293/353	246/268	303/347		188/238	123/160	168/231
Hardness								
Geometric Mean/Spread Factor	mg/L-CaCO <sub>3</sub>	N = 285	N = 32	N = 55		N = 344	N = 344	N = 333
Arithmetic Mean/Standard Deviation		151/1.39	150/1.18	194/1.20		130/1.42	81.3/1.13	129/1.26
Median/90 Percentile		155/31	152/22	197/43		135/31	81.9/10.2	132/30
		153/199	156/174	190/227		138/174	80/95	133/170
Calcium								
Geometric Mean/Spread Factor	mg/L	N = 280	N = 32	N = 55		N = 345	N = 344	N = 334
Arithmetic Mean/Standard Deviation		48/1.22	49.3/1.18	68.7/1.27		40.3/1.25	25.3/1.15	39.3/1.26
Median/90 Percentile		48.9/9.43	49.9/7.4	70.8/19.7		41.3/8.9	25.6/3.8	40.3/9.2
		47.1/63.8	51.7/56.8	65.9/87.4		42.3/53.4	25.0/30.5	40.1/51.9
Magnesium								
Geometric Mean/Spread Factor	mg/L	N = 279	N = 32	N = 55		N = 343	N = 344	N = 333
Arithmetic Mean/Standard Deviation		8.0/1.24	6.6/1.19	4.3/1.86		7.6/1.32	4.3/1.14	7.4/1.31
Median/90 Percentile		8.2/1.7	5.7/1.1	5.0/2.4		7.9/2.2	4.4/0.55	7.7/2.1
		8.0/10.5	6.8/7.9	5.4/8.2		7.5/11.0	4.4/5.0	7.4/10.7
Sodium								
Geometric Mean/Spread Factor	mg/L	N = 280	N = 32	N = 55		N = 345	N = 344	N = 334
Arithmetic Mean/Standard Deviation	(Rec'd=20)	29.2/1.25	22.0/1.44	31.6/1.15		11.5/1.60	11.5/1.38	11.4/1.57
Median/90 Percentile		30.0/6.5	23.2/5.9	31.9/4.3		12.9/6.2	12.1/4.1	12.6/5.8
		29.8/37.4	24.9/28.2	33.3/36.2		11.4/22.6	11.9/14.5	11.3/20.7
Bromide								
Geometric Mean/Spread Factor	mg/L	115/2822	5/28	49/53		66/341	54/107	15/105
Arithmetic Mean/Standard Deviation		0.0022/8.81	0.0004/10.49	0.022/3.22		0.0003/19.10	0.0032/3.76	0.0032/3.76
Median/90 Percentile		.011/0.068	0.0044/0.0096	0.039/0.044		0.0060/0.0117	0.0072/0.0108	<0.0030/0.002
		<0.003/0.035	<0.003/0.014	0.031/0.080		<0.003/0.020	0.003/0.016	<0.003/0.008
Chloride								
Geometric Mean/Spread Factor	mg/L	N = 284	N = 28	N = 53		N = 341	N = 107	N = 105
Arithmetic Mean/Standard Deviation	(SMCL=250)	46.4/1.28	39.7/1.65	60.8/1.14		20.1/1.39	21.1/1.41	34.4/1.32
Median/90 Percentile		47.8/11.4	43.4/13.7	61.3/7.3		21.2/6.9	22.5/8.5	35.7/9.8
		48.0/60.5	47.0/54.0	63.0/68.0		20.0/30.0	20.0/38.0	36.0/47.0
Cyanide								
Geometric Mean/Spread Factor	mg/L	75/283	0/32	8/53		13/346	25/109	16/105
Arithmetic Mean/Standard Deviation		0.0024/3.32	<0.005	0.0021/2.34		--	0.0022/3.14	0.0019/2.55
Median/90 Percentile		0.0054/0.0098	<0.005	<0.0050		<0.0050	<0.0050	<0.0050
		<0.005/0.011	<0.005/<0.005	<0.005/0.006		<0.005/0.005	<0.005/0.009	<0.005/0.007

## Major Cations, Anions, and Nutrients

TABLE 9.3-2 (Cont'd)

Parameter	Units	NEWTP					WTP1	WTP2	WTP3
		Phase IA	Phase IB	Phase IIA					
Fluoride									
Geometric Mean/Spread Factor	mg/L	277/283	25/28	53/53	340/340	107/107	105/105		
Arithmetic Mean/Standard Deviation	(MCL = 1.5 to 2.4)	0.30/1.44	0.28/1.56	0.47/1.26	0.90/1.19	0.94/1.12	0.88/1.32		
Median/90 Percentile		0.32/0.12	0.25/0.10	0.48/0.11	0.92/0.19	0.95/0.11	0.90/0.15		
		0.3/0.4	0.3/0.4	0.5/0.6	0.9/1.0	0.9/1.1	0.9/1.0		
Nitrogen: Nitrate, Nitrite									
Geometric Mean/Spread Factor	mg/L-N	284/285	28/28	53/53	327/341	89/105	100/104		
Arithmetic Mean/Standard Deviation	(MCL=10)	6.9/1.65	5.1/1.87	7.7/1.31	1.09/2.72	0.44/5.60	1.3/2.68		
Median/90 Percentile		7.4/2.1	5.9/2.3	7.9/1.6	1.4/0.7	0.87/0.64	1.6/0.7		
		7.6/9.3	6.9/8.0	8.3/9.6	1.4/2.2	0.9/1.7	1.6/2.5		
Nitrogen, Ammonia									
Geometric Mean/Spread Factor	mg/L	65/285	9/28	N = 53	N = 341	N = 105	N = 103		
Arithmetic Mean/Standard Deviation		0.002/15.96	0.008/5.86	0.49/3.60	0.005/6.03	0.44/1.83	0.019/6.99		
Median/90 Percentile		0.069/0.211	0.046/0.123	0.73/0.41	0.026/0.083	0.99/0.22	0.096/0.256		
		<0.02/0.06	<0.02/0.07	0.80/1.20	<0.02/0.05	0.45/0.76	<0.02/0.20		
Sulfate									
Geometric Mean/Spread Factor	mg/L	N = 284	N = 28	N = 53	N = 341	N = 107	N = 105		
Arithmetic Mean/Standard Deviation	(SMCL=250)	91.1/1.20	59.5/1.15	54.6/1.21	51.0/1.34	29.8/1.14	31.0/1.38		
Median/90 Percentile		92.7/17.4	60.1/7.8	55.6/10.7	53.4/16.8	30.1/3.83	32.7/10.7		
		90.0/118.9	62.0/69.0	55.4/71.0	47.1/82.0	30.0/34.9	30.0/49.0		

1.  $N$  = Number of Samples (All Above Detection Limit).
2.  $115/282$  = Number Above Detection Limit/Number of Samples (typical).
3. Geometric Mean not calculated if less than 15 percent of samples were above the detection limit.



## Major Cations, Anions, and Nutrients

TABLE 9.3-3

APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES IN GEOMETRIC MEANS FOR MAJOR CATIONS, ANIONS AND NUTRIENTS IN FINISHED WATERS<sup>1</sup>

Constituent	Highest Geometric Mean at Local WTP	Phase of EEWTP Operation	Geometric Mean at EEWTP	Number of Degrees of Freedom	T	t-statistic for 0.05 Significance Level	Significant Difference
Total Dissolved Solids	182.4	Alum-1A Alum-1B Lime-1A	299.4 231.1 301.5	55.7 38.4 86.1	16.59 5.53 18.47	1.67 1.68 1.66	WTP1 < EEWTP WTP1 < EEWTP WTP1 < EEWTP
Sodium	11.53	Alum-1A Alum-1B Lime-1A	29.2 22.0 31.57	340.3 40.1 204.3	32.48 9.33 31.92	1.64 1.68 1.64	WTP1 < EEWTP WTP1 < EEWTP WTP1 < EEWTP
Chloride	34.36	Alum-1A Alum-1B Lime-1A	5.37 39.68 30.78	107.5 30.3 95.1	9.73 1.46 17.54	1.66 1.70 1.66	WTP3 < EEWTP No Signif. Diff. WTP3 < EEWTP
Cyanide	0.0022	Alum-1A Alum-1B <sup>2</sup> Lime-1A	0.0024 — 0.0021	114.2 — 82.8	0.66 — -0.29	1.66 — 1.67	No Signif. Diff. — No Signif. Diff.
Fluoride	0.94	Alum-1A Alum-1B Lime-1A	0.30 0.23 0.47	175.5 27.1 57.9	-47.02 -6.81 -20.64	1.64 1.70 1.67	EEWTP < WTP2 EEWTP < WTP2 EEWTP < WTP2
Nitrate, Nitrite	1.28	Alum-1A Alum-1B Lime-1A	6.87 5.09 7.71	103.5 51.2 101.4	16.62 9.04 17.34	1.66 1.67 1.66	WTP3 < EEWTP WTP3 < EEWTP WTP3 < EEWTP
Ammonia Nitrogen	0.435	Alum-1A Alum-1B Lime-1A	0.002 0.008 0.491	206.8 28.2 57.5	-30.87 -11.78 0.65	1.64 1.70 1.67	EEWTP < WTP2 No Signif. Diff. No Signif. Diff.
Sulfate	51.04	Alum-1A Alum-1B Lime-1A	91.10 59.52 54.61	333.2 46.8 85.7	30.19 4.99 2.21	1.64 1.68 1.67	WTP1 < EEWTP WTP1 < EEWTP WTP1 < EEWTP
Bromide	0.0032	Alum-1A Alum-1B Lime-1A	0.0022 0.0004 0.0224	126.1 30.3 76.4	-2.05 -4.50 9.47	1.66 1.70 1.66	EEWTP < WTP2 EEWTP < WTP2 WTP2 < EEWTP
Hardness	130.4	Alum-1A Alum-1B Lime-1A	150.7 150.5 193.7	323.0 59.7 110.2	5.30 4.12 12.8	1.64 1.67 1.66	WTP1 < EEWTP WTP1 < EEWTP WTP1 < EEWTP

1. Hypothesis testing as described in Appendix B. One sided t-test at 0.05 significance level.
2. Insufficient quantified data for estimation of geometric mean in EEWTP finished water.

## Major Cations, Anions, and Nutrients

TABLE 9.3-4  
MAJOR CATIONS, ANIONS, AND NUTRIENTS IN EEWTP  
FINISHED WATERS COMPARED TO NIPDWR MCLS  
AND SECONDARY MCLS

Parameter	No. Exceeding MCL/ No. of Samples	Percent Exceeding	Upper 95% Conf. of % Exceeding	Lower 95% Conf. of % Exceeding
Fluoride; MCL = 1.5-2.4 mg/L <sup>1</sup>				
Alum-IA	0/283	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime-IA	0/53	0.0	--	--
Nitrate + Nitrite; MCL for Nitrate = 10 mg/L-N				
Alum-IA	10/285	3.51	6.28	1.70
Alum-IB	0/29	0.0	--	--
Lime-IA	1/53	1.89	10.10	0.0478
Total Dissolved Solids; SMCL = 500 mg/L				
Alum-IA	0/216	0.0	--	--
Alum-IB	0/28	0.0	--	--
Lime-IA	1/53	1.89	10.10	0.0478
Chloride; SMCL = 250 mg/L				
Alum-IA	0/284	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime-IA	0/53	0.0	--	--
Sulfate; SMCL = 250 mg/L				
Alum-IA	0/284	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime-IA	0/53	0.0	--	--

1. MCL depends on water temperature; 1.5 mg/L used.

AD-A136 864

OPERATION MAINTENANCE AND PERFORMANCE EVALUATION OF THE  
POTOMAC ESTUARY E. (U) MONTGOMERY (JAMES M) CONSULTING  
ENGINEERS INC PASADENA CA J M MONTGOMERY SEP 83

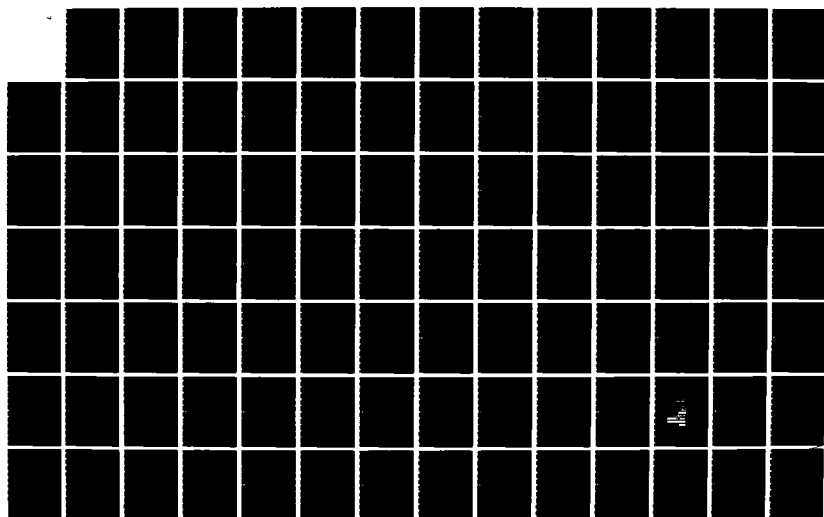
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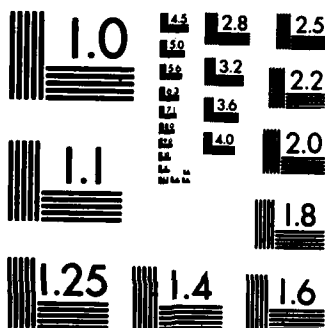
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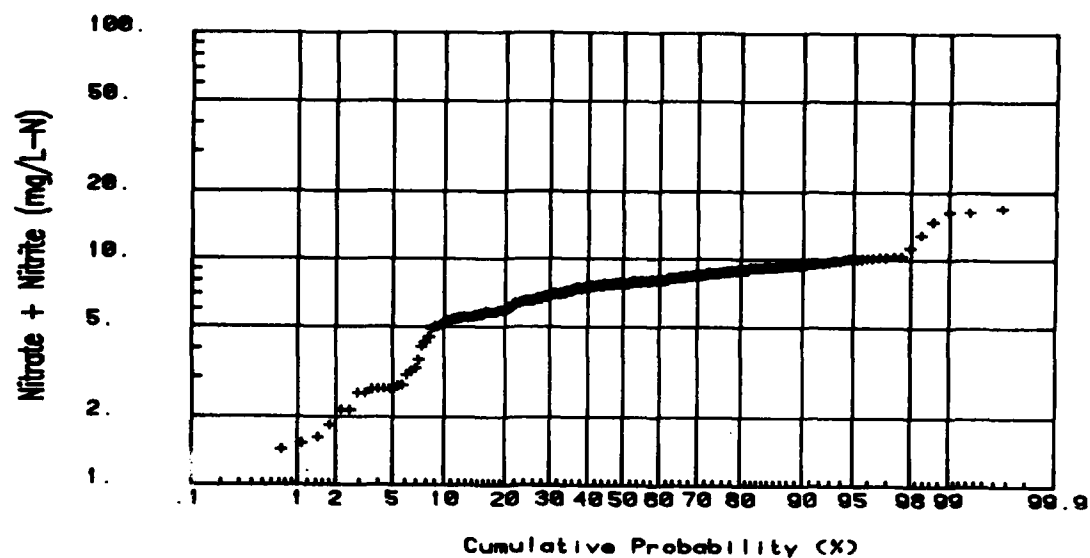
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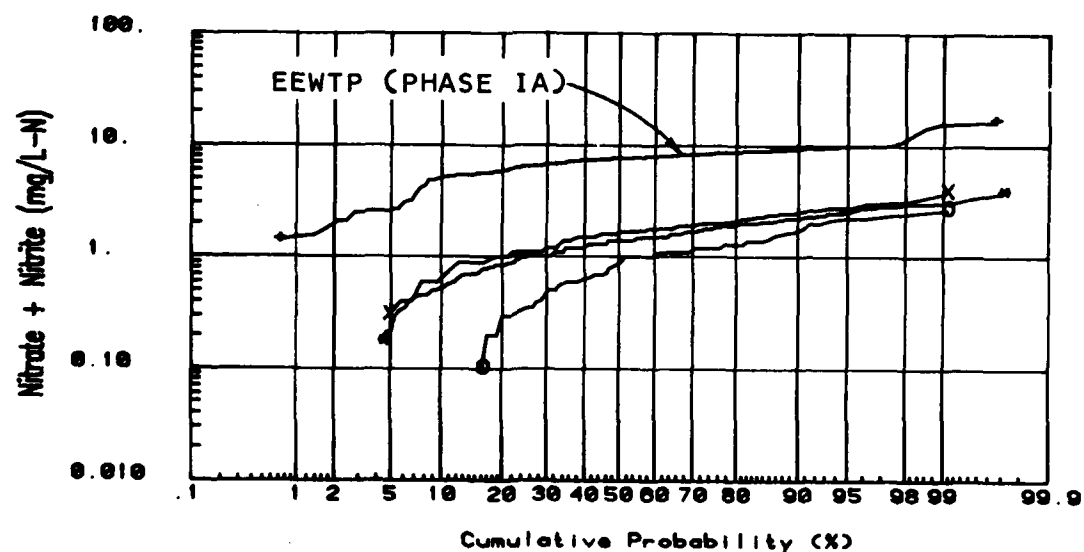




MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A



(a) Nitrate + Nitrite in EEWTP finished water  
(16 March 1981 to 16 March 1982 - Phase IA)



(b) Nitrate + Nitrite in EEWTP finished water (Phase IA)  
and at three local WTPs (all available data)

**NITRATE + NITRITE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
(PHASE IA)  
FIGURE 9. 3-1**

# Major Cations, Anions, and Nutrients

TABLE 9.3-4  
MAJOR CATIONS, ANIONS, AND NUTRIENTS IN EEWTP  
FINISHED WATERS COMPARED TO NIPDWR MCLS  
AND SECONDARY MCLS

Parameter	No. Exceeding MCL/ No. of Samples	Percent Exceeding	Upper 95% Conf. of % Exceeding	Lower 95% Conf. of % Exceeding
Fluoride; MCL = 1.5-2.4 mg/L <sup>1</sup>				
Alum-IA	0/283	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime-IIA	0/53	0.0	--	--
Nitrate + Nitrite; MCL for Nitrate = 10 mg/L-N				
Alum-IA	10/285	3.51	6.28	1.70
Alum-IB	0/29	0.0	--	--
Lime-IIA	1/53	1.89	10.10	0.0478
Total Dissolved Solids; SMCL = 500 mg/L				
Alum-IA	0/216	0.0	--	--
Alum-IB	0/28	0.0	--	--
Lime-IIA	1/53	1.89	10.10	0.0478
Chloride; SMCL = 250 mg/L				
Alum-IA	0/284	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime IIA	0/53	0.0	--	--
Sulfate; SMCL = 250 mg/L				
Alum-IA	0/284	0.0	--	--
Alum-IB	0/29	0.0	--	--
Lime-IIA	0/53	0.0	--	--

1. MCL depends on water temperature; 1.5 mg/L used.

### Fluoride

Excessive intake of fluoride can result in mottling of dental enamel and minor changes in bone density. Epidemiological studies received by the EPA prior to establishing an interim MCL showed a temperature dependence of these physiological effects. The NIPDWR MCL was therefore established to account for temperature effects and ranges from 1.4 - 2.4 mg/L for a corresponding temperature range of 32.5°C down to less than 12.0°C.

Because fluoridation of EEWTP water was never practiced and because influent water was low in fluoride, the fluoride standard was never exceeded. The geometric mean concentration of fluoride was significantly lower in EEWTP finished water than in the local treated supplies and, therefore, was not a parameter of concern.

### Nitrate

The NIPDWR include an MCL for nitrate of 10 mg/L as N. Nitrate itself is only toxic at extremely high levels on the order of parts per thousand. Some portion of the nitrate ingested is, however, converted to nitrite by bacteria in the human stomach by bacteria. The yield of this conversion tends to increase with higher pH in the stomach. Because of the more alkaline condition in infant stomachs, the toxicity of nitrite in the stomach is almost always observed in infants rather than in adults. This toxic effect is known as methemoglobinemia; nitrite in the bloodstream combines with hemoglobin to form methemoglobin which does not have an adequate oxygen-carrying capacity. When the level of methemoglobin in the blood increases from the normal levels of less than two percent to more than five percent, effects such as decreased muscle function, anoxia, and death can occur. Consumption of water with a high concentration of nitrate for as short a period as a day may result in the occurrence of methemoglobinemia. The basis for the federal primary standard is the observation that measureable increases in methemoglobin levels in infants took place when nitrate intake was over 2.2 mg of nitrate nitrogen per kilogram of body weight. This intake can be reached when a baby is fed a dehydrated formula made with water that the mother boiled (increasing the concentration), if the water initially contains 10 mg/L of nitrate nitrogen (EPA, 1975b).

Alum Phase. The NIPDWR standard for nitrate of 10 mg/L as N was exceeded in ten out of 285, or 3.5 percent of samples in Phase IA. The 95 percent confidence bounds around this estimate of the fraction exceeding the MCL are 1.7 percent and 6.3 percent. Because high concentrations of nitrate in drinking water are known to be associated with acute toxicity, this is a matter which deserves closer examination.

Figure 9.3-1 shows frequency distributions of concentrations of nitrate plus nitrite measured in EEWTP finished water during Phase IA and in local finished waters during the entire sampling program. Nitrite is assumed to be present at negligible concentrations compared to nitrate since nitrite is rapidly oxidized to nitrate by hypochlorous acid. The plot for EEWTP finished water lies above the plots for other finished waters by large amounts. The geometric mean

## Major Cations, Anions, and Nutrients

concentration of nitrate plus nitrite in the EEWTP during Phase IA is significantly above those of all three local WTPs. Figure 9.3-2 shows the concentrations of nitrate plus nitrite in EEWTP finished water during both Phases IA and IB, along with data from WTP3. Although none of the samples out of 29 had concentrations greater than the federal primary standard, during Phase IB, the values still remained above the highest local plant.

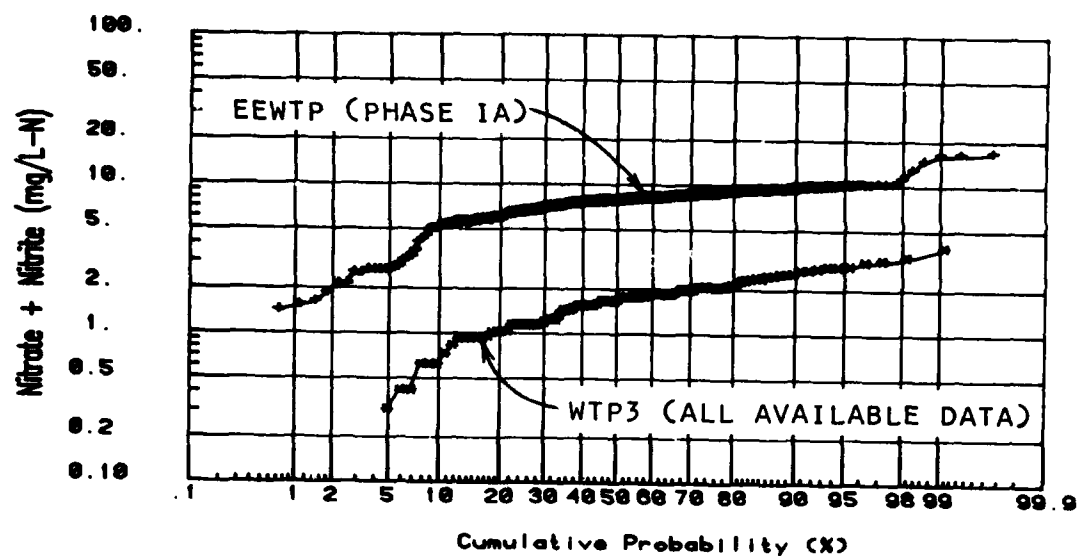
As indicated in Chapter 6 of this report, maximum influent nitrate levels at the EEWTP were higher than the maximum levels projected to occur in the Potomac River estuary under drought conditions. Nitrate in EEWTP finished water occurs at high levels because of the high concentrations of nitrate present in the Blue Plains treated wastewater. The Blue Plains treatment plant uses a nitrification step which converts much of the ammonium and organic nitrogen present in sewage to nitrate nitrogen. In fact, all ten of the finished water samples in excess of the Federal MCL occurred on days of high influent nitrate, when the EEWTP was operating on the Blue Plains source alone (see Chapter 7).

Other public water utilities in the U.S. show higher nitrate values than those from the local WTPs. EPA data show that as many as 371 water supply systems in the U.S. (out of about 220,000) had violations of the MCL in 1981. Most problems with nitrate in drinking water take place in groundwater, because of areas where agricultural fertilization has led to nitrate contamination of aquifers. Previous surveys of public water supplies had shown approximately five percent of communities exceeding the 10 mg/L (as N) standard in 1961 (Taylor, 1963) and two percent exceeding the old USPHS limit of 45 mg/L as  $\text{NO}_3$  (10 mg/L as N) in 1969 (McCabe).

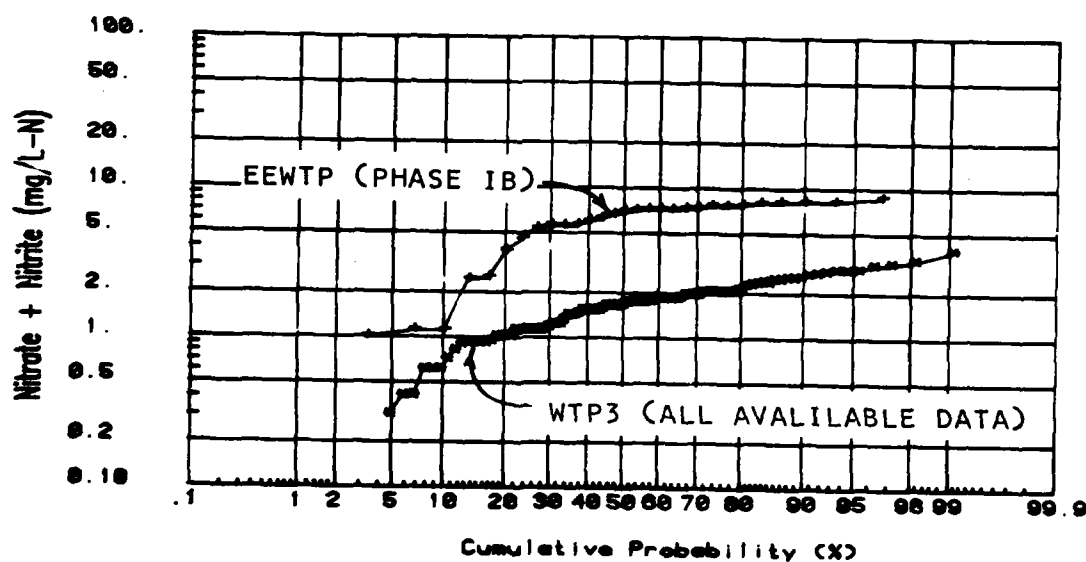
Because nitrate is relatively unaffected by the treatment processes employed at the EEWTP, finished water quality is directly related to the quality of the influent water. It is possible that, due to higher dilution effects or altered operation at the Blue Plains plant, the nitrate levels in the influent to a full-scale estuary plant would be lower than those observed in the monitoring program. This would be especially true if denitrification were to be implemented at Blue Plains to convert nitrates to nitrogen gas. Prior to construction of a full-scale drinking water plant on the Potomac Estuary, a full assessment of Blue Plains effluent nitrate levels and more precise modeling efforts (formulated to account for the non-conservative nature of this parameter) should be undertaken.

In summary, the fact that nitrate was present in EEWTP finished water at levels which exceed 10 mg/L as N is a source of concern with respect to its potential for causing methemoglobinemia. As stated by the EPA (1975b) "Treatment methods to reduce the nitrate content of drinking water are being developed and should be applied . . . if another source of water cannot be used. If a water supply cannot maintain the  $\text{NO}_3\text{-N}$  concentration below the limit, diligent efforts must be made to assure that the water is not used for infant feeding." However, the infrequent high levels observed in the EEWTP finished water all occurred during use of 100 percent Blue Plains source water, and are not deemed as sufficient cause to reject the estuary as a source; the





(a) Nitrate + Nitrite in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and WTP3 finished water (all available data)



(b) Nitrate + Nitrite in EEWTP finished water (16 March 1982 to 6 July 1982 - Phase IB) and WTP3 finished water (all available data)

**NITRATE + NITRITE IN EEWTP FINISHED WATER  
COMPARED TO RESULTS FROM WTP3  
(PHASES IA AND IB)  
FIGURE 9. 3-2**

## Major Cations, Anions, and Nutrients

blended influent, as monitored does not warrant an additional process for nitrate removal. In the design of an estuary plant, however, the actual level of nitrates projected for the estuary under future drought conditions should be studied. High levels, if any, could be attenuated through the blending of estuary plant finished water with water from other supplies.

Lime Phase. None of the treatment processes employed at the EEWTP were expected to reduce incoming nitrate levels. The results obtained during Phase IIA operations are not significantly different from those obtained during Phase IA. As Table 9.3-4 shows, the NIPDWR MCL for nitrate was exceeded in one out of 53, or in 1.89 percent of the samples taken during Phase IIA. In addition, the distribution of values obtained remained well above the three local plants (Figure 9.3-3).

These results present the same concerns presented above for Phase IA, and the same discussion applies.

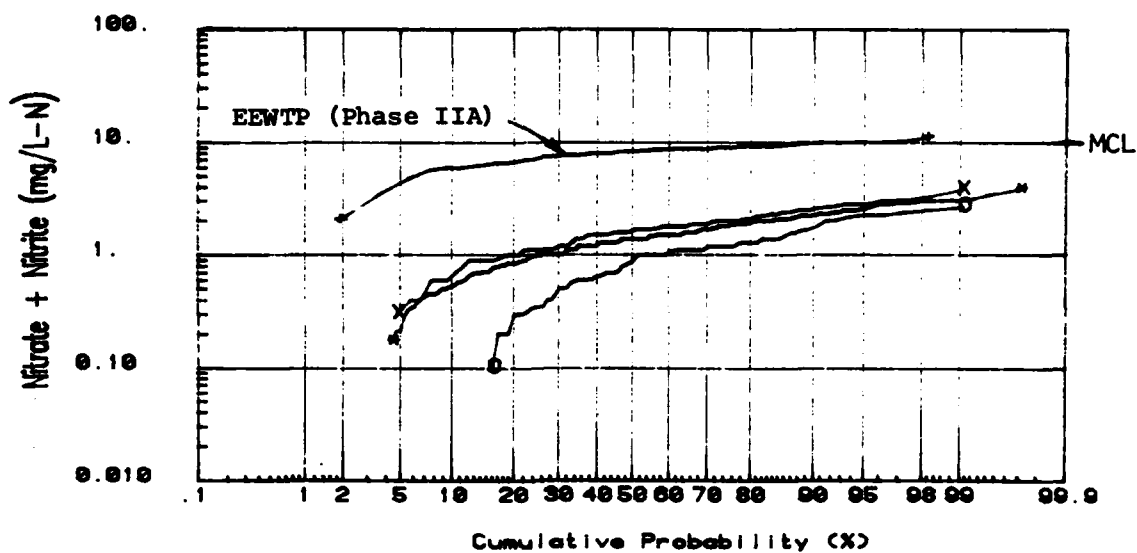
### MAJOR CATIONS, ANIONS, AND NUTRIENTS WITH SECONDARY STANDARDS

For various mineral parameters, secondary drinking water standards have been promulgated by the EPA on the basis of aesthetic effects experienced by consumers. These include total dissolved solids (TDS), chloride, and sulfate, for which high concentrations are associated with salty tastes. In addition, the EPA has promulgated a monitoring requirement for sodium. However, there is no MCL for sodium in drinking water because there are insufficient data available on the health significance. There is, instead, a suggested recommended level, such that concentrations below 20 mg/L of sodium would be considered "optimal." Table 9.3-4 shows the secondary MCLs and the frequency with which they and the recommended level for sodium were exceeded. None of the federal secondary MCLs were exceeded during Phase IA. During Phase IIA, one sample exceeded the secondary MCL for TDS. The recommended level for sodium was exceeded, however, in nearly all samples. These parameters are discussed below.

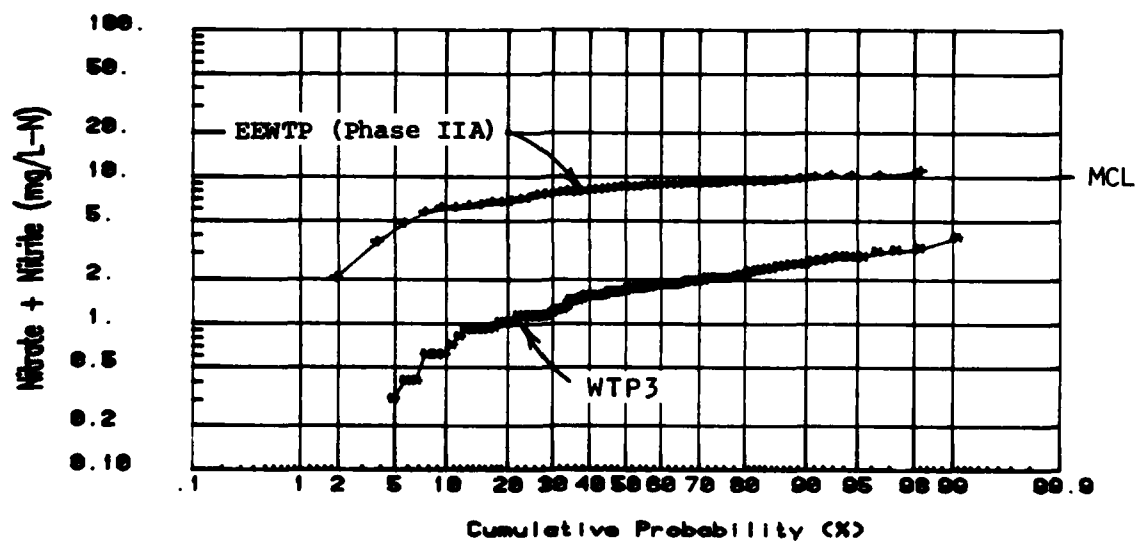
#### Total Dissolved Solids

TDS represents the sum of several individual mineral parameters. As an overall measure of dissolved minerals, TDS has effects on consumer acceptance and industrial use. The 500 mg/L secondary MCL is set on the basis of taste threshold.

Alum Phase. In all samples taken during Phase IA the concentration of TDS never exceeded the federal secondary standard of 500 mg/L. However, as previously shown in Tables 9.3-1 and 9.3-2, the concentrations in EEWTP finished water were typically above those found in local plants. The probability distributions of TDS levels in the EEWTP during Phase IA and in the local finished waters during the entire monitoring program are shown in Figure 9.3-4(a). The geometric mean of TDS concentration in the EEWTP during Phase IA was above that in all of the local plants at the 0.05 significance level. This is



(a) Nitrate plus Nitrite Results in EEWTP Finished Water (Phase IIA) and at Three Local WTPs



(b) Nitrate plus Nitrite Results in EEWTP Finished Water (Phase IIA) compared to Results from WTP 3.

**NITRATE + NITRITE IN EEWTP FINISHED WATER  
AND AT LOCAL WTPs  
(PHASE IIA)  
FIGURE 9. 3-3**

## Major Cations, Anions, and Nutrients

not unexpected for a plant which uses an influent containing 50 percent treated wastewater, the amounts of minerals of various kinds which are added to water as a result of domestic use are well documented.

Since all measured values of TDS in EEWTP treated water during Phase IA are below the 500 mg/L level, salty tastes related to overall mineralization of the finished water are unlikely. Many communities in the U.S. use waters containing more than 2,000 mg/L of TDS because no better water is available.

No specific health effects would be expected from the total dissolved solids levels measured in EEWTP finished water. The higher levels of TDS in this water than in the local MWA supplies could have effects on industrial uses of water.

Lime Phase. One TDS sample out of 53 taken during Phase IIA exceeded the secondary MCL, while as Figure 9.3-4(b) illustrates, most of the others ranged between 200 and 400 mg/L. These values are substantially higher than those which typically occur in the three local plants, and a comparison of the geometric means of the EEWTP and WTP1 (the worst local plant) confirms this difference at the 0.05 significance level.

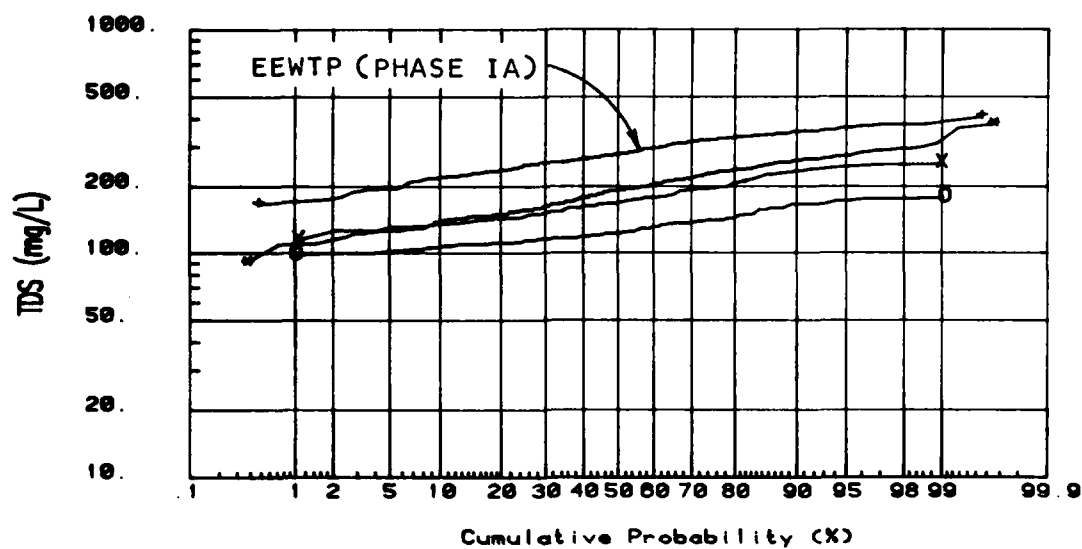
No health effects could be associated with this level of TDS; however consumers switching to such a higher TDS water from one of the other local plants might initially perceive a difference in taste. The higher TDS could also force industries to alter or augment pretreatment for certain processes.

### Chloride

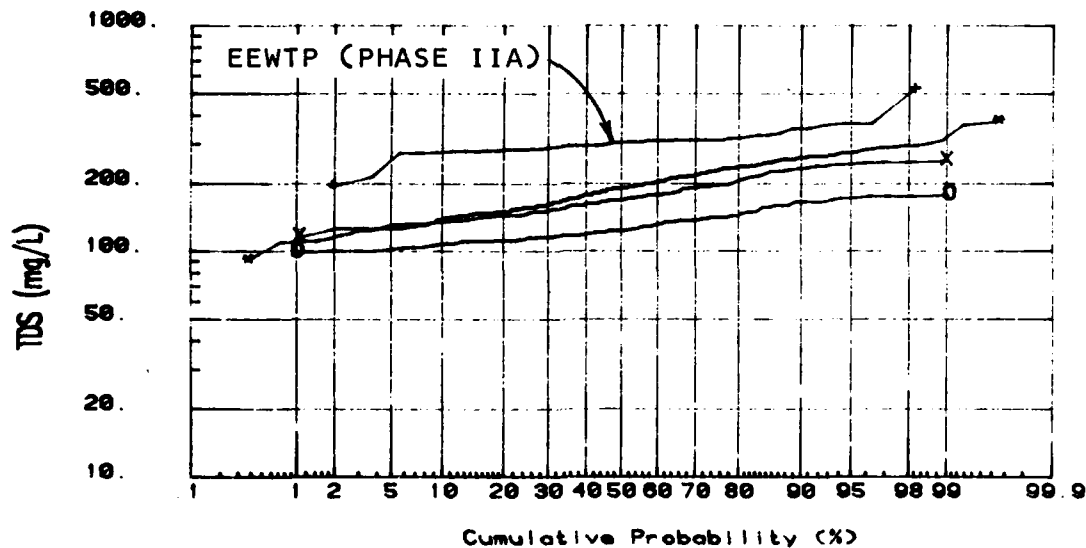
The basis for the federal secondary MCL for chloride of 250 mg/L is not public health but rather consumer acceptance and economic impact. The taste threshold for chloride ion in drinking water ranges from roughly 100 to 700 mg/L depending on the individual and other conditions. The other bases for the secondary MCL are the impacts that chloride in industrial water use has on corrosivity of process water, and the toxicity to plants irrigated with high chloride water.

Data for chloride concentrations measured in the EEWTP finished water in local finished waters during Phases IA and IIA are shown in Figure 9.3-5. The level of chloride at the EEWTP never exceeded the secondary MCL. The geometric mean concentration of chloride level in the EEWTP is, however, significantly greater than that for local WTPs. Again, chloride is higher in EEWTP finished water because of the use increment loading in Blue Plains wastewater.

It is unlikely that the range of levels observed in EEWTP finished water, nearly all below 100 mg/L, would result in significant perception of salty taste by users except possibly in an initial switch from one of the local plants to the EEWTP.

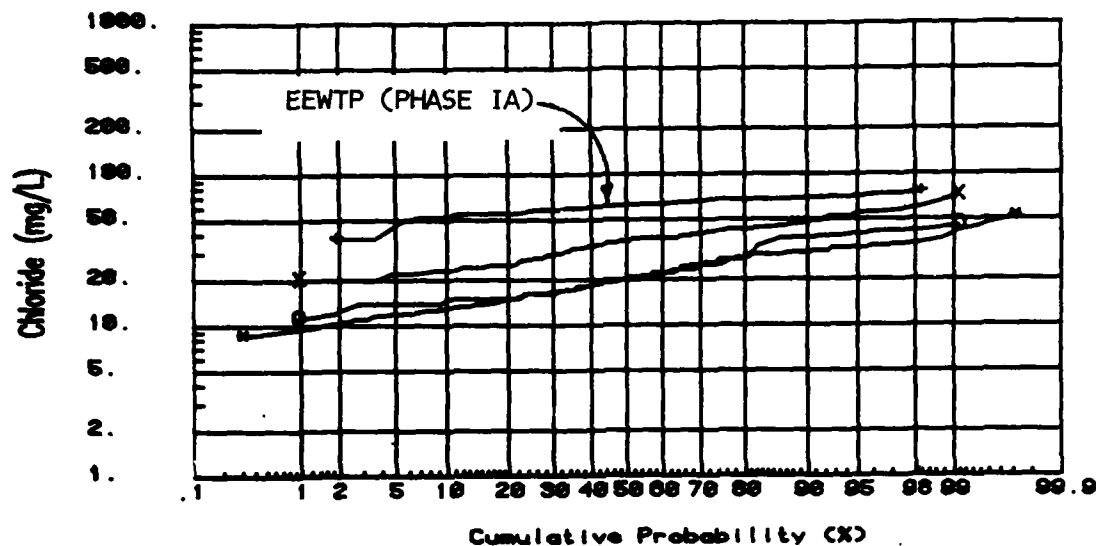


(a) Total dissolved solids in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)

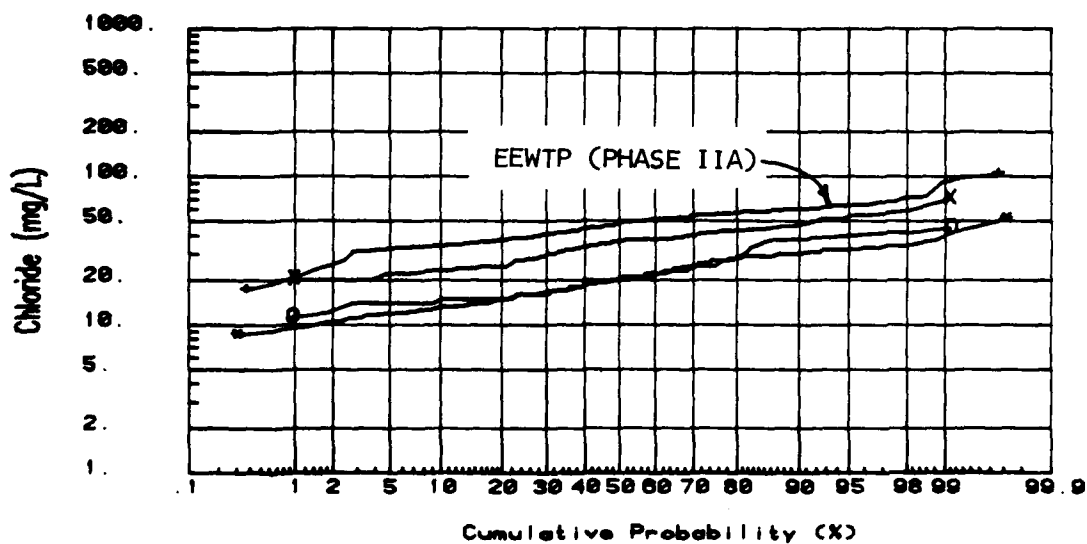


(b) Total dissolved solids in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**TOTAL DISSOLVED SOLIDS IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-4**



(a) Chloride in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)



(b) Chloride in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**CHLORIDE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-5**

### Sulfate

The secondary standard for sulfate relates to taste and other physiological effects. The threshold for taste for sulfate in water is roughly 200 mg/L to 400 mg/L, while physiological effects of sulfate such as laxative action do not take effect until the concentration exceeds 1,000 mg/L.

Alum Phase. The data for sulfate concentration measured in EEWTP finished water and in local plants are shown in Figure 9.3-6(a). None of the measured concentrations exceeded the federal secondary MCL of 250 mg/L. However, the geometric mean level of sulfate in EEWTP finished water is significantly above that of the local plants. This results both from the sulfate use in treatment in treated wastewater and from the use of alum as coagulant which elevated sulfate levels during treatment.

Despite an increase of 40 to 60 mg/L between the geometric means in local plants and Phase IA EEWTP finished water, the values observed are well below the taste threshold for sulfate. Thus it is unlikely that Phase IA EEWTP finished water would cause perceptions of salty taste among consumers. Similarly, the values are well below those potentially causing physiological effects.

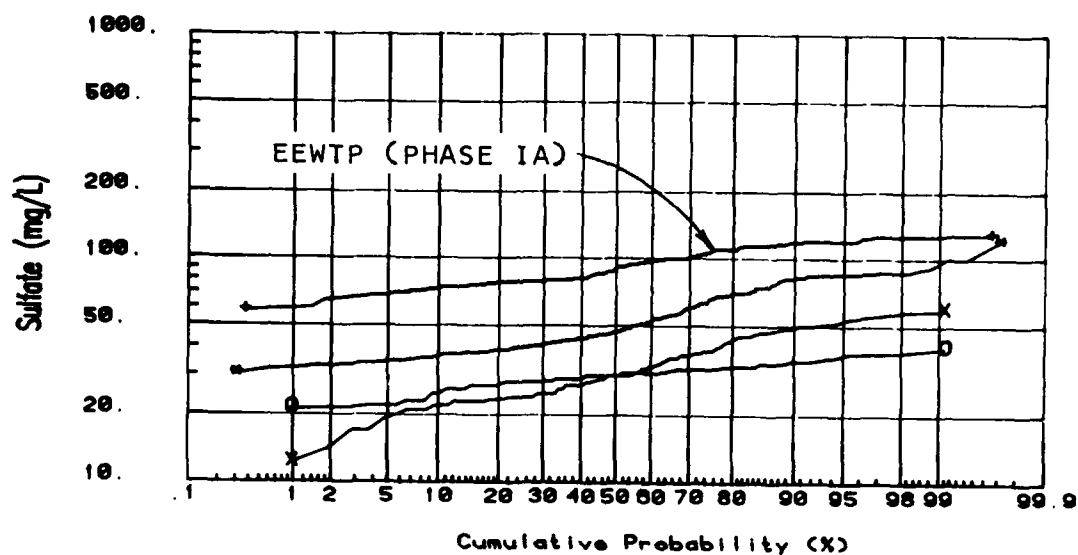
Lime Phase. With the use of lime instead of alum as the primary coagulant during Phase IIA, EEWTP finished water sulfate levels were reduced. As previously shown in Table 9.3-2, the geometric mean dropped from 91 mg/L during Phase IA to 55 mg/L during Phase IIA.

Relative to the local WTPs, Table 9.3-2 shows the EEWTP values to be only slightly higher overall, although a test of the geometric means of Phase IIA EEWTP finished water and WTP1 does show that the EEWTP water is significantly higher at the 0.05 significance level. Figure 9.3-6 indicates this difference, but also shows that levels in a local plant's finished water reached higher maximum values (Figure 9.3-6(b)).

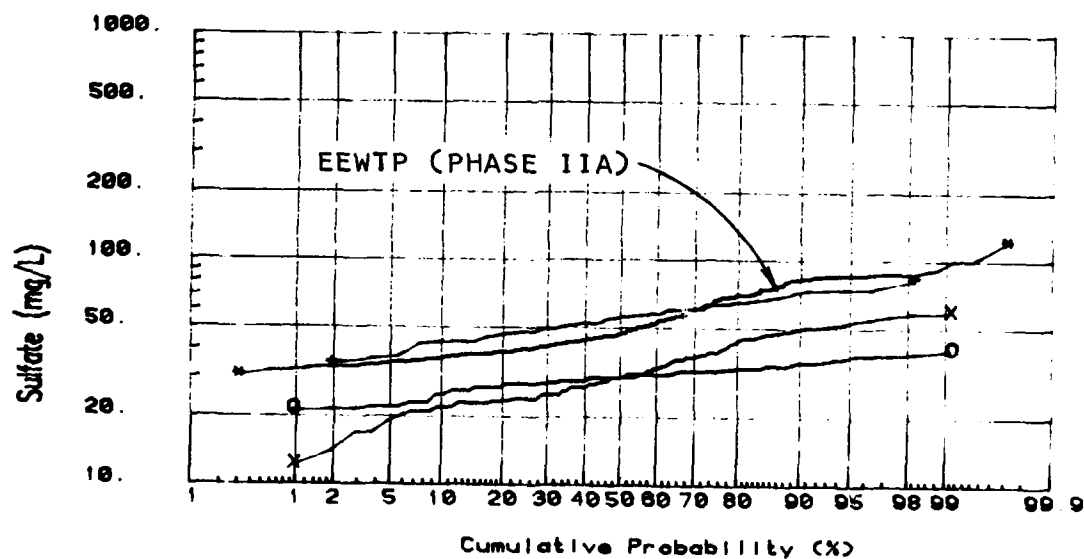
These results indicate that the finished waters obtained during both alum and lime phases do not pose a concern for health or consumer acceptance, with respect to sulfate.

### Sodium

Dietary sodium does not have a significant effect on the healthy population at intakes of up to 2,000 to 4,000 mg/day; its adverse effects are principally confined to sensitive segments of the population. This includes individuals who suffer from diseases such as congestive heart failure, cirrhosis, or renal disease which are induced or aggravated by high salt intake, as well as those who suffer from hypertension (high blood pressure), or who are genetically predisposed to hypertension. For individuals in this category, recommended sodium intake levels range from less than 500 mg/day for those on extremely restricted low-sodium diets to 2000 mg/day.



(a) Sulfate in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Sulfate in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**SULFATE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-6**



The National Academy of Sciences has suggested that forty percent of the population would benefit if total dietary sodium intake were less than 2,000 mg/day. This would focus on reduction of salt added to food, consumption of foods lower in sodium, and reducing the level of sodium in drinking water.

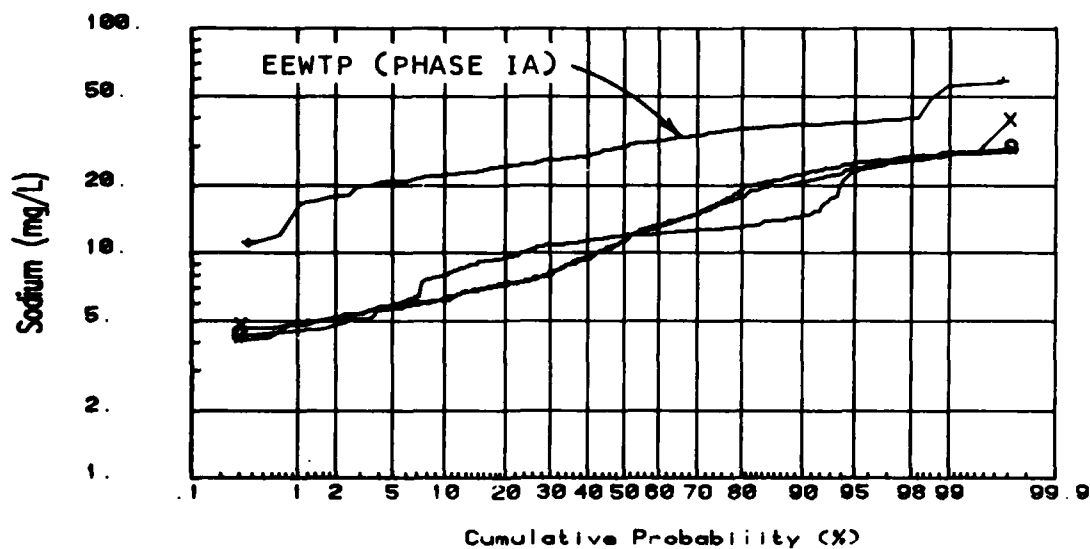
The American Heart Association recommends a maximum of 21 mg/L of sodium in drinking water. With average adult fluid intake of 1.5 to 3 L/day, the percent contribution of water having a sodium concentration of 21 mg/L to a daily intake of 2,000 mg/day would be from 1.5 to 3 percent. However, for the most sensitive risk group for which intake must be limited to less than 500 mg/L, the contribution of drinking water to dietary sodium would be up to twelve percent of daily intake.

Sodium in the diet can have significant physiological effects on certain sensitive parts of the human population. As a result of ongoing research into the effects of dietary sodium, the EPA promulgated, in the 1980 amendments to the National Interim Primary Drinking Water Regulations (NIPDWR), sampling requirements for sodium of at least annually for community water supply systems using surface water sources (EPA, 1980c). However, the EPA did not promulgate a standard or a maximum contaminant level. Instead, a recommendation was stated that "sodium levels of 20 mg/L or less in drinking water be considered as optimal."

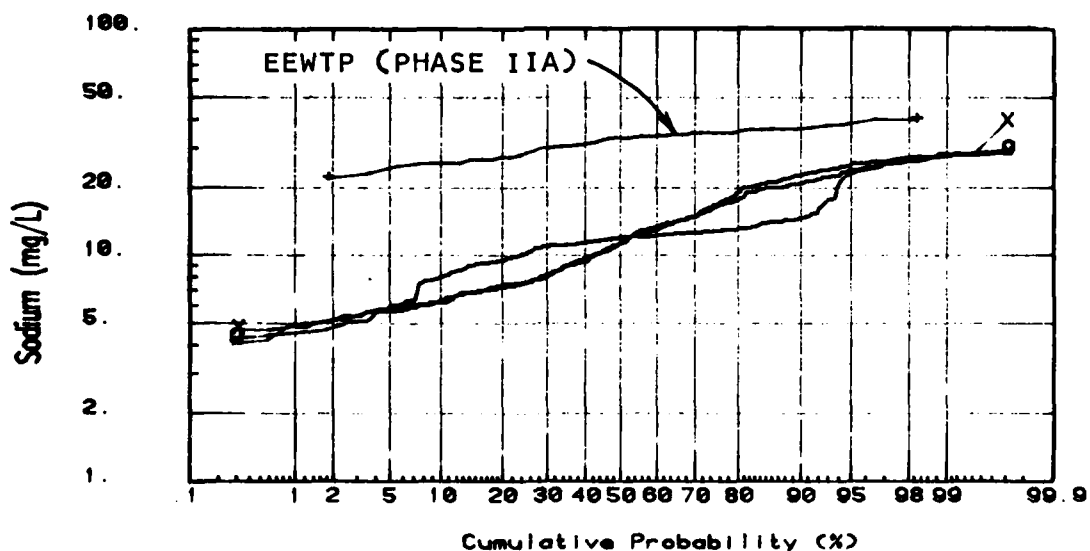
Alum Phase. Data for sodium in EEWTP finished water during Phase IA and in the local WTPs during the entire monitoring period are shown in Figure 9.3-7. The levels of sodium in EEWTP finished water are clearly higher than in local MWA supplies. The geometric mean concentration of sodium is significantly higher in the EEWTP than in the local finished waters. Moreover, the suggested level of 20 mg/L was exceeded in EEWTP finished water in 270 out of 280, or 96 percent of samples during Phase IA. 95 percent confidence bounds around this estimate for the population are 94 percent and 98 percent. Clearly the EEWTP finished water is likely to fall above the optimum range of sodium concentrations recommended by EPA nearly all of the time. Sodium hydroxide addition for pH control, which began in February of 1982, generally contributed between 3 and 4 mg/L of sodium to the water.

With an average sodium level in EEWTP finished water of about 30 mg/L, the contribution to dietary sodium in the most sensitive risk group (requiring a maximum daily intake of 500 mg Na) would be up to eighteen percent. When sodium concentration in EEWTP finished water is at its highest observed value of about 58 mg/L, the contribution would be up to 35 percent. For this group the EEWTP water would probably be unacceptable and a special source would be recommended. However, this risk group comprises a very small segment of the population.

Approximately three percent of the population is on sodium-restricted diets with intake limited to less than 2,000 mg/day (NAS, 1977). For this group, even the highest observed sodium level in EEWTP Phase IA water would correspond to contribution from drinking water of only about nine percent. The average



(a) Sodium in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Sodium in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**SODIUM IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-7**

## Major Cations, Anions, and Nutrients

observed sodium level would represent about four percent or less of dietary intake.

Research on the relationship of sodium to hypertension is continuing. Two surveys of sodium levels in public water supplies showed that approximately 42 percent of supplies contained more than 20 mg/L sodium. A 1967 survey of 2,100 water supplies, covering half the population of the U.S., showed that 23 percent of the supplies had more than 50 mg/L sodium. The level of sodium in EEWTP finished water, therefore, is not unusual when compared to existing drinking water supplies across the country. However, sodium in this supply presents a concern for public health which should be addressed if EEWTP water supply is to supplement the existing metropolitan Washington supplies.

Lime Phase. Although the maximum values of sodium observed during Phase IIA were lower than those from Phase IA, the mean values for the two phases were similar (29.2 for Phase IA and 31.9 for Phase IIA). As Figures 9.3-7(a) and (b) show, EEWTP finished water sodium levels during the two phases remained relatively comparable except at the very low and very high percentile values. Conventional water treatment processes typically do not remove sodium; such similar results would be expected.

Conclusions presented above for the alum phase sodium results are thus directly applicable to the lime phase as well. Sodium levels under either treatment process would represent the same basic fraction of total daily sodium intake for the consumer population. Inasmuch as these levels are both above the suggested optimum level of 20 mg/L, they represent a matter of concern for a full-scale plant.

### OTHER MAJOR CATIONS, ANIONS, AND NUTRIENTS OF HEALTH SIGNIFICANCE

Some parameters with direct or indirect potential health effects and which do not have NIPDWR MCLs or secondary MCLs include ammonia, cyanide, bromide, and hardness (composed of calcium and magnesium). These parameters are discussed individually below.

#### Ammonia

Measurement of ammonia during EEWTP operation was by the phenol-hypochlorite method which does not distinguish between free ammonia and ammonia present as chloramine. Since there was free chlorine in nearly all EEWTP finished water samples, most of the ammonia measurements are actually of chloramine. As Figures 9.3-8(a) and (b) show, the concentration of ammonia or chloramine as N ranges up to 2 mg/L. This corresponds to approximately 2.6 mg/L ammonia as  $\text{NH}_4$  or 7.4 mg/L monochloramine, the predominant chloramine species which would be present under typical EEWTP operating conditions.

Ammonia itself has no direct health effect in drinking water except at extremely high levels. The odor threshold for ammonia has been estimated to be as low as 0.04 mg/L. The significance of ammonia for health effects is

## Major Cations, Anions, and Nutrients

indirect in the sense that ammonia combines with chlorine to form chloramines, and reduces the amount of free chlorine available for disinfection. Levels of ammonia observed during Phase IA and IB did appear to impact disinfection efficiency, as discussed in Chapter 7. Minimization of this problem requires sufficient chlorine addition (as an intermediate oxidant) to reduce ammonia levels below detection limits. This practice was utilized during periods of Phase IA operation, in December through March, 1981.

The known health effect of chloramine in finished water is hemolytic anemia in patients who undergo kidney dialysis where the dialyzing fluid uses tap water containing chloramines. In this condition, red blood cells are oxidized and the level of methemoglobin increases in the blood, reducing the oxygen-carrying capacity of the blood. Several water utilities in the U.S. (including one of those monitored for this study) now employ chloramination as the method of maintaining disinfectant residual in water distribution systems. Typically they work with dialysis facilities and/or patients to ensure removal of the chloramines ahead of the dialysis unit. Research on other potential health effects of chloramines is continuing. The NAS has suggested a no-adverse-response-level of 0.125 mg/L for 7-day exposure, but this is based on very limited information and corresponds to health studies where no effects at all were observed. Consequently, there are no current EPA regulations on chloramines in drinking water.

Alum Phase. Measurement of ammonia in EEWTP finished water during Phase IA showed only about 23 percent of the samples above the detection limit of 0.02 mg/L. Within the detected values, the concentration of chloramine (ammonia) ranges up to approximately 1.4 mg/L as N. However, the 90th percentile value is only 0.05 mg/L as N, indicating a highly skewed population of predominantly low values.

As shown in Tables 9.3-1 and 9.3-2, the level of ammonia in EEWTP finished water during Phase IA is lower than in WTP2. A hypothesis test on the geometric mean shows that the EEWTP concentration is significantly lower than in WTP2 at the 0.05 significance level.

It may be concluded that the issue of chloramine effects on kidney dialysis patients should be investigated if the water supply were to contain levels of chloramine as measured in the small fraction of samples with detectable levels taken during Phase IA. However, as was indicated above, many water utilities intentionally leave chloramine residuals for disinfection, and have successfully surmounted any dialysis problems with chloramines by coordinating with health authorities.

With respect to potential ammonia associated odors, despite the fact that values above the cited threshold level of 0.04 were obtained, none of the odor tests reported ammonia as the type of odor detected. Again, this points to the fact that chloramines, rather than free ammonia, were present in the EEWTP finished water.

**Lime Phase.** During Phase IIA, chloramines were added to EEWTP finished water after ozonation, as a source of disinfectant residual. As Table 9.3-2 and Figure 9.3-8 show, the resulting chloramine levels in EEWTP finished water were substantially higher than those obtained during Phase IA. In addition, approximately 85 percent of the samples taken were higher than all of the local plants.

Despite these higher values, conclusions with respect to potential effects on consumers remain the same. The levels are not high enough to create any known health effects except for kidney dialysis patients. Considerations expressed above for Phase IA results in this regard pertain to Phase IIA as well. Again, no reported ammonia type odors were reported, indicating the likelihood that all ammonia was present as chloramines.

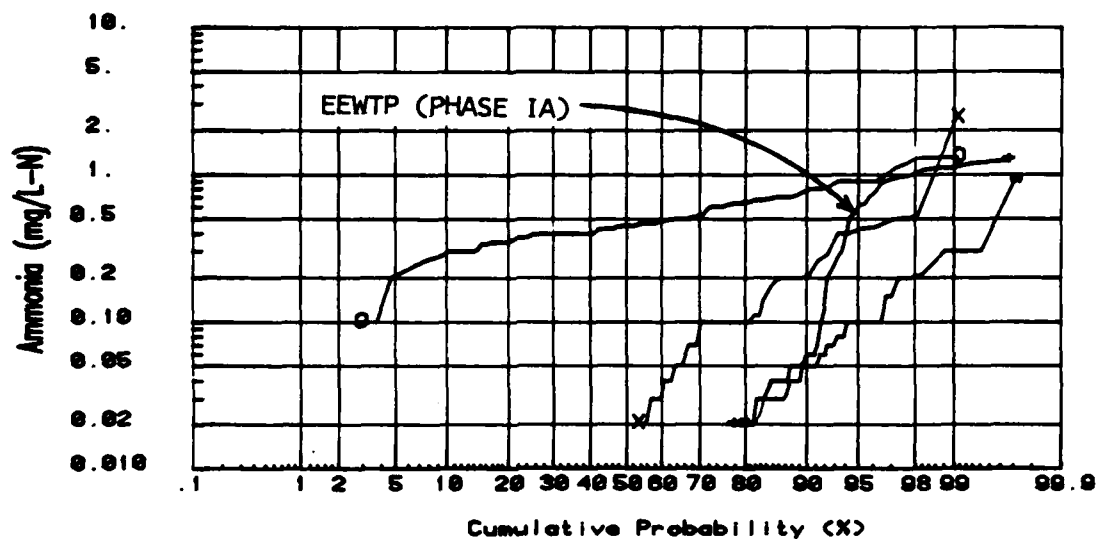
### Cyanide

Cyanide (CN) is a well-known poison which has acute toxic effects when ingested at sufficient doses. Chronic effects are not observed; small doses are metabolized to thiocyanate in the liver and eliminated in the urine. The EPA recommended water quality criterion for cyanide is 0.2 mg/L. A decision was made not to regulate cyanide within the NIPDWR because EPA surveys of finished water supplies detected only trace amounts, and because chlorine reacts rapidly with cyanide to generate harmless thiocyanate. The 0.2 mg/L criterion allows a significant margin of safety. The lethal dose has been observed to be about 570 µg/kg. This translates to 40 mg/L CN for a 165 pound person consuming one liter per day. As is shown below, levels in EEWTP finished water during both alum and lime phases do not approach this value.

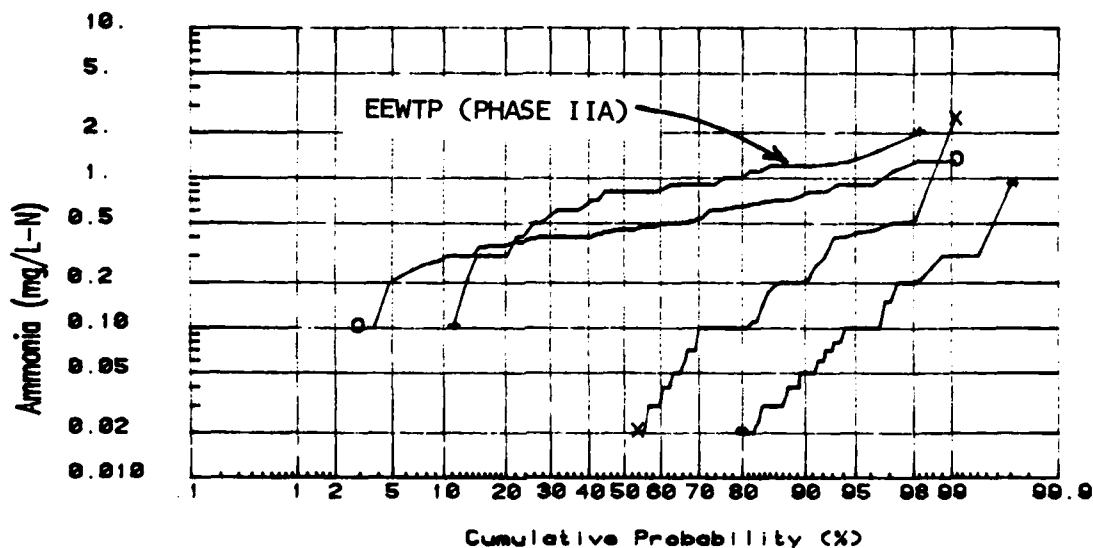
As shown in Table 9.3-2, the median value for cyanide in the EEWTP finished water during Phases IA and IIA were slightly higher than in local plants. The same is true for the geometric mean and the arithmetic mean. This suggests that a closer examination of the data is appropriate. Figures 9.3-9(a) and (b) show probability plots of cyanide concentrations as measured in EEWTP finished water during Phases IA and IIA.

Hypothesis testing on the geometric mean concentrations shows that, although the EEWTP geometric mean cyanide levels are higher than that for WTP2 (the highest local plant), this difference is not statistically significant at the 0.05 level (Table 9.3-3). Also, these estimates of geometric mean concentrations were made through the use of the maximum-likelihood algorithm based on positive values (see Appendix B). Only about one-quarter of the samples of EEWTP finished water during the two phases were above the cyanide detection limit of 0.005 mg/L.

Cyanide present in drinking water at these levels would not be toxic and would likely be disposed of indefinitely in the body. Higher intake levels are typically derived from natural food sources such as cabbage. Moreover, the concentrations of cyanide in the EEWTP finished water and in local plants are not much different. Therefore, cyanide does not pose a significant concern for human health at the observed levels.

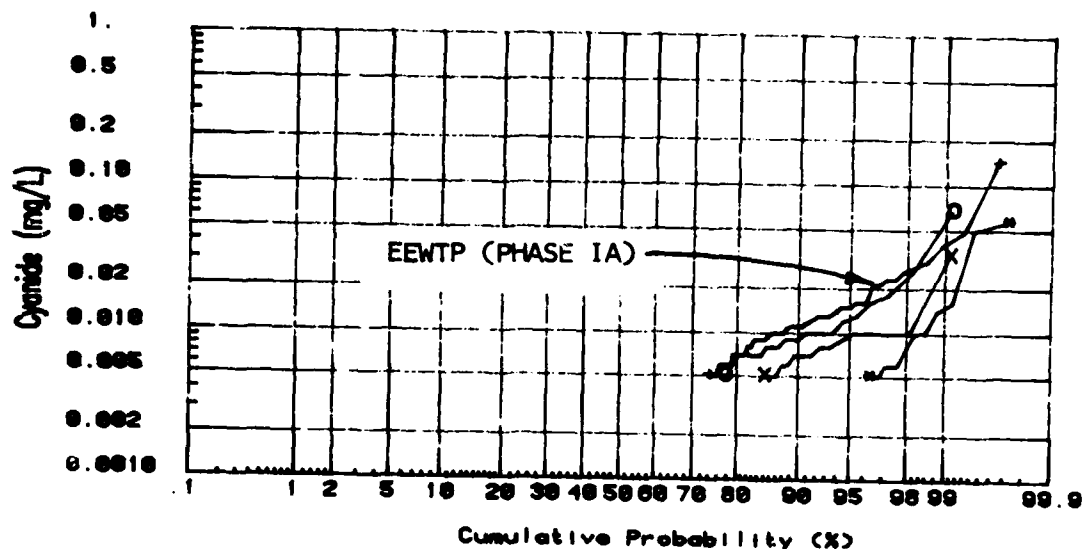


(a) Ammonia in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)

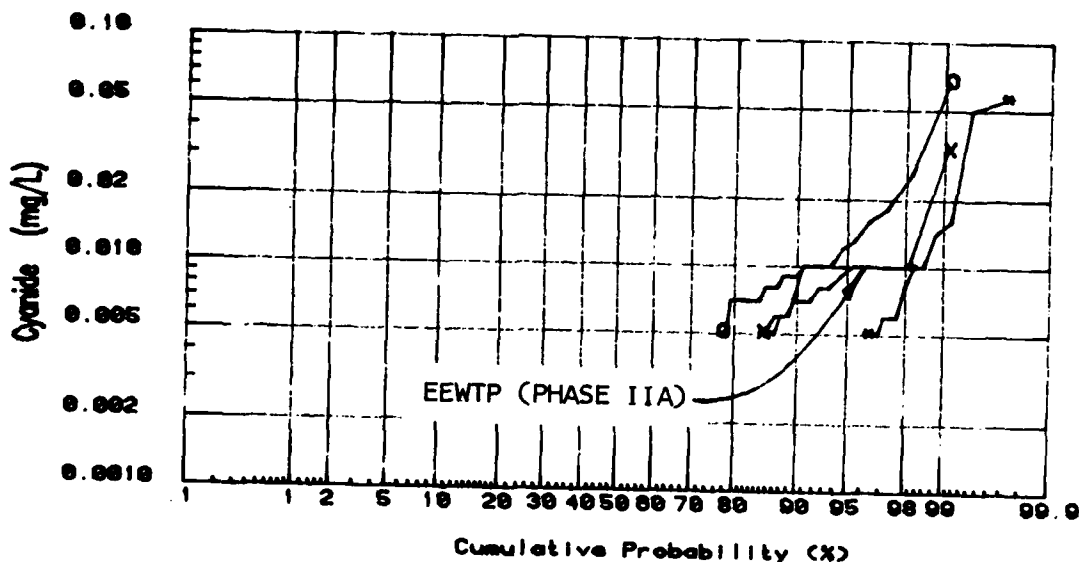


(b) Ammonia in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**AMMONIA IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-8**



(a) Cyanide in EEWTP Finished Water (Phase IA) and at Three Local WTPs (All Available Data)



(b) Cyanide in EEWTP Finished Water (Phase IIA) and at Three Local WTPs (All Available Data)

**CYANIDE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
(PHASE IIA)  
FIGURE 9. 3-9**

### Bromide

Bromide toxicity occurs only at high levels. The NAS has suggested a no-adverse-response level of 2.3 mg/L, well above levels found in EEWTP finished water. Bromide can affect consumers' health indirectly through its role in trihalomethane (THM) formation. If bromide is present when chlorine is added to water containing humic acids or other THM precursor material, brominated species of trihalomethanes are formed. Since bromide has higher molecular weight than chlorine, the effect of substituting bromine for chlorine in the THM molecule is to increase the concentration of THM's in mass units. However, as is discussed below, measurements of both bromide and trihalomethanes in EEWTP finished water were low, and the concentrations of trihalomethanes were also lower than occurred in the local plants (see Section 7 of this chapter). Neither direct toxicity nor indirect THM effects appear to be a source of concern.

Alum Phase. As is shown in Figure 9.3-10(a), only 40 percent of the 282 samples analyzed for bromide during Phase IA were above the 0.003 mg/L detection limit. Because a greater fraction of samples from WTP 2 were above this limit, the geometric mean value for WTP 2 is higher than that for Phase IA finished water (Table 9.3-2) even though, as Figure 9.3-10(a) illustrates, the detected values for the EEWTP were all greater than those from the local plants.

In terms of direct health effects, these slightly higher EEWTP values are not significant; the maximum value of approximately 0.10 mg/L is still far below the NAS recommended level of 2.3 mg/L. In addition, as was indicated above, the difference in brominated THM species between the EEWTP and the local plants is not significant at the low THM values observed.

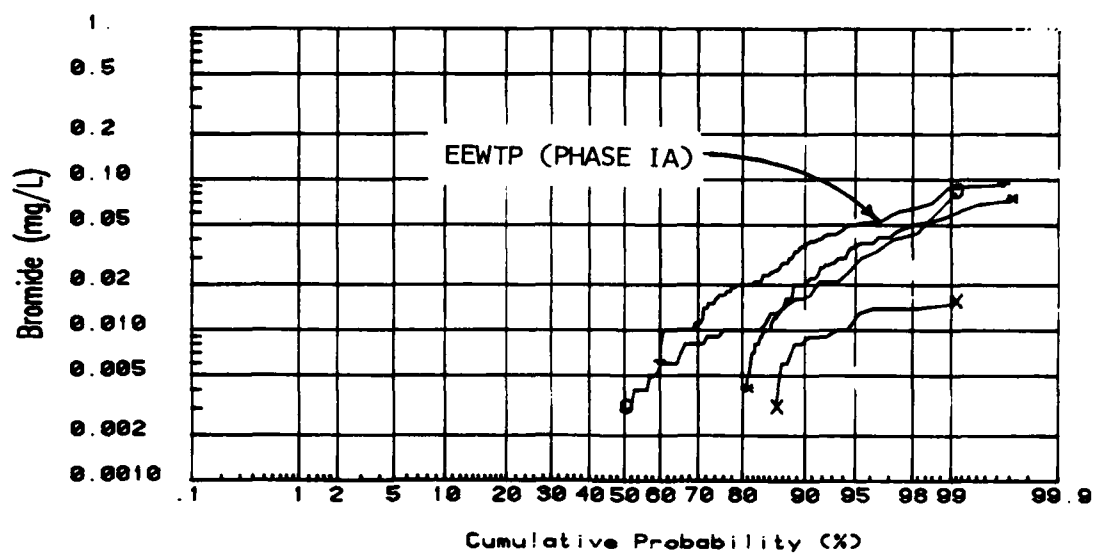
Lime Phase. The same health effect conclusions that were made for Phase IA can be made for levels observed during Phase IIA. Although the latter values are somewhat higher, reaching a maximum of about 0.3 mg/L, and showing a greater proportion of detected values (about 92 percent), they still do not create cause for concern. The reason for the higher values is the lack of intermediate oxidant and the change in final disinfectant. Thus, although influent bromide levels during Phases IA and IIA were comparable (geometric means of 0.057 and 0.031, respectively), free chlorine was available during Phase IA to reduce incoming levels by an order of magnitude, while during Phase IIA essentially no decrease occurred.

### Hardness, Calcium, and Magnesium

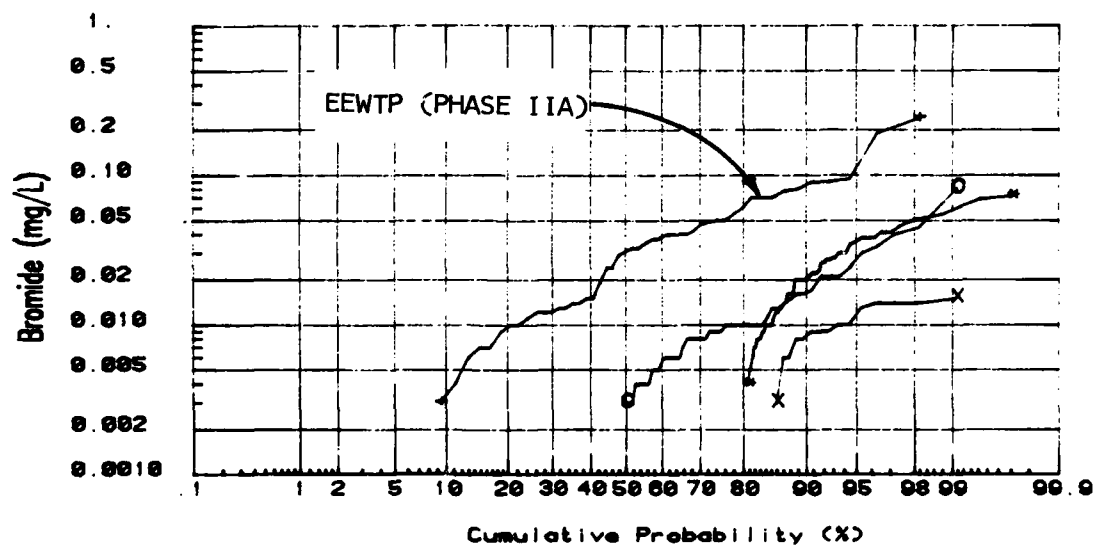
Hardness in drinking water consists of two predominant cations, calcium and magnesium. Hardness is defined as the sum of polyvalent cations expressed in units of equivalent concentration as calcium carbonate.

The principal concern with respect to hardness is one of consumer acceptance, primarily in terms of the water's suitability for cleansing and industrial uses. "Hard" waters are generally considered to be those which require considerable





(a.) Bromide in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)



(b) Bromide in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**BROMIDE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 3-10**

## Major Cations, Anions, and Nutrients

amounts of soap to form lather or which produce scale in boilers, hot water heaters, and other units which raise the water temperature. Because of these and other adverse effects, such as "bathtub ring", deterioration of fabric, and, in some cases, stains, hard waters may be undesirable for certain domestic or industrial applications. Generally, a "hard" water can be defined as one with greater than 200 mg/L of hardness (as  $\text{CaCO}_3$ ). Hardness values in the range of 100 to 200 mg/L constitute a "moderately hard" water, while waters with hardness below 100 mg/L are generally considered as "soft". These ranges are illustrative only. The suitability of a given water with respect to hardness will vary depending upon the particular consumer and intended use. With respect to drinking water and health, hard waters are considered as satisfactory for human consumption as soft waters, with some indication of potential benefit, as discussed below.

Research on the health effects of hardness in drinking water is an ongoing activity. Recent reviews of the epidemiological literature by EPA and NAS demonstrate that a cause-and-effect relationship between hardness and health is not yet proven. Generally, reports have shown an inverse correlation between the incidence of cardiovascular disease and the level of hardness in drinking water such that in areas with hard water there is decreased cardiovascular diseases and related mortality. The credibility of such studies depend mostly on observed consistent trends of findings rather than biological plausibility as to mechanism or statistical significance.

Some hypotheses about the relationship between hardness and cardiovascular function include:

1. Protective effect from bulk constituents of hard water.

There is evidence to suggest that calcium and/or magnesium may play a role in protecting against cardiovascular disease. An increase in calcium in the diet may be associated with lower levels of blood serum lipids; a deficiency of magnesium may cause elevation in blood lipids and cholesterol esters. Increased magnesium intakes may decrease the development of cardiac and atherosclerotic lesions.

2. Protective action of trace elements in hard water.

A limited number of studies suggest that minor constituents which are associated with hard water may exert a beneficial effect on the cardiovascular system. Some trace elements suggested for this role include vanadium, lithium, manganese, and chromium.

3. Harmful elements in soft water.

Soft water tends to be more corrosive to plumbing systems than hard water. As a result, certain trace elements tend to be found in higher concentrations in soft than in hard water as measured at the tap. Several such metals have been suggested as possible intermediaries in the increased cardiovascular disease rates sometimes associated with soft

water. Some elements suggested as possible actors in the induction of cardiovascular disease, on the basis of very limited data, include cadmium, lead, copper, and zinc. These metals often occur in plumbing materials and have been found to leach into soft drinking water.

It is not clear whether drinking water can provide enough of either potentially beneficial or harmful elements to have any significant impact on the pathogenesis of cardiovascular diseases when compared to total intake through other dietary or environmental pathways. Even hard water with concentrations of calcium and magnesium on the order of levels found in EEWTP finished water would typically supply less than ten percent of the total dietary intake of calcium and magnesium.

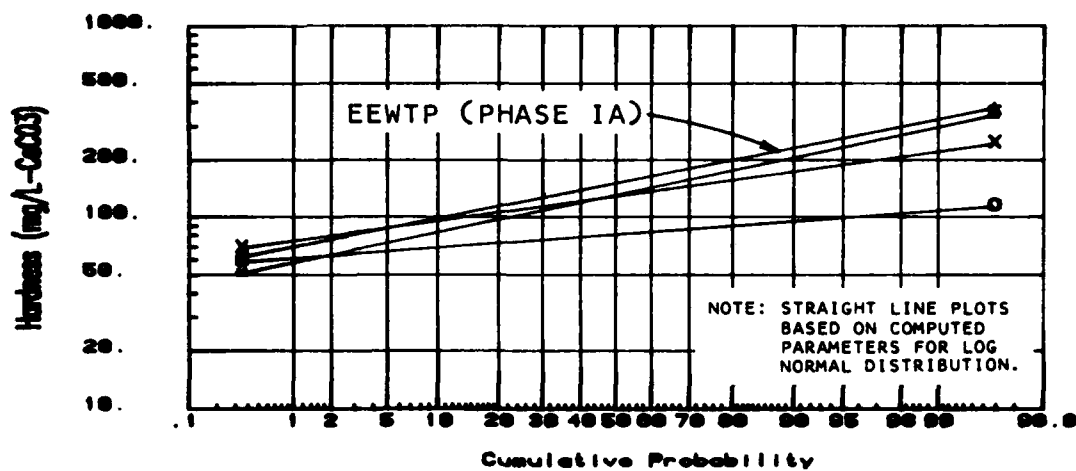
Given the current status of knowledge about the correlation between hardness and lower rates of cardiovascular disease, the EPA has not thought it appropriate at this time to recommend a policy to modify the hardness or softness of public water supplies. However, moratoria on softening plants have been implemented in Britain, Canada, and the Netherlands.

Alum Phase. As shown in Table 9.3-2, the geometric and arithmetic mean concentrations of calcium, magnesium, and hardness are higher in the EEWTP finished water during Phase IA than in any local finished water. This results principally from the use increment in calcium concentration during domestic use.

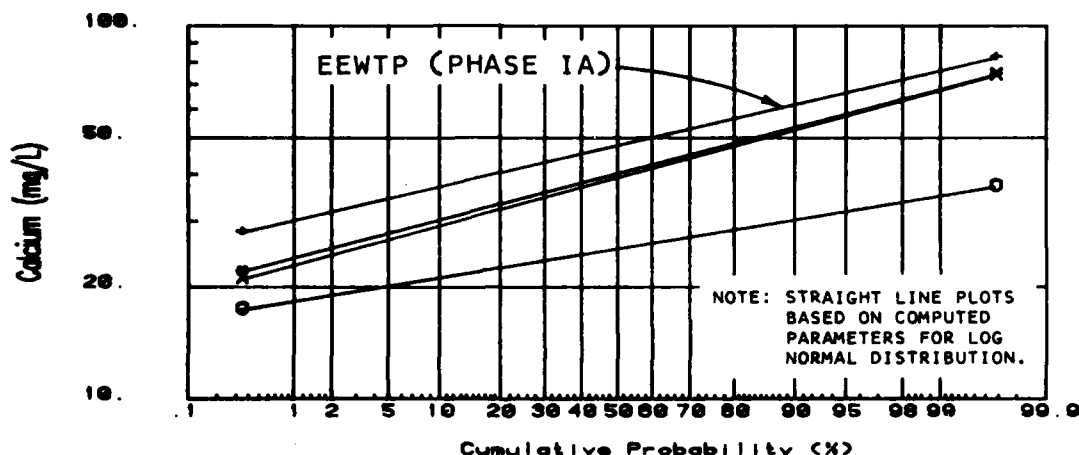
The probability plots of hardness, calcium, and magnesium in the EEWTP finished water during Phase IA and in the other finished waters during the entire monitoring program are shown in Figure 9.3-11. The data for calcium in the EEWTP are clearly higher in concentration than in local plants. Similarly, the values for hardness are higher in the EEWTP for most percentiles than in the local plants; the plots for magnesium are less distinctly different among plants.

It appears unlikely that levels of hardness in the EEWTP finished water during Phase IA, compared to local plants, would relate to a negative health effect. Other effects of hardness in water, such as detrimental economic impacts on soap consumption and industrial processes, could occur. The difference in average hardness between the EEWTP and the local WTP with the hardest water is about 20 mg/L- $\text{CaCO}_3$ , which may be significant in economic terms. However, the arithmetic average level of hardness of 155 mg/L- $\text{CaCO}_3$  is not extremely high when compared to national levels of hardness. For example, a 1962 survey of the hundred largest cities in the U.S. showed that 27 of these cities had hardness in raw water of more than 180 mg/L.

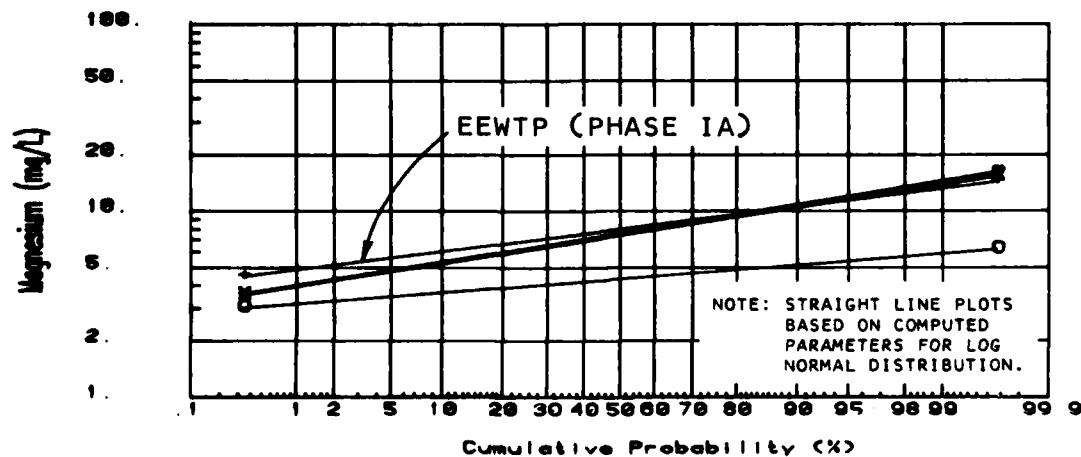
Lime Phase. The use of lime adds an increment of calcium, and hence hardness to the EEWTP finished water. As Table 9.3-2 indicates, all measures of both calcium and hardness are higher than those which were obtained for Phase IA and for the local plants in the MWA. Magnesium values were slightly lower, indicating some removal within the lime clarification.



(a) Hardness in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Calcium in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(c) Magnesium in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)

# **HARDNESS, CALCIUM AND MAGNESIUM IN EEWTP FINISHED WATER (PHASE IA) AND AT THREE LOCAL WTPs**

Figures 9.3-12(a), (b) and (c) illustrate the increased discrepancy between the hardness and calcium values obtained at the EEWTP and the local WTPs during Phase IIA. Because of the potential inverse role of hardness in cardiovascular disease, such an increase is not of concern from a health standpoint. Consumer costs which have been associated with increasingly hard water (e.g., increased soap costs, in-house softeners), would likely occur, but to an unknown degree. Factors affecting the magnitude of this effect include previously experienced levels of hardness and socioeconomic status.

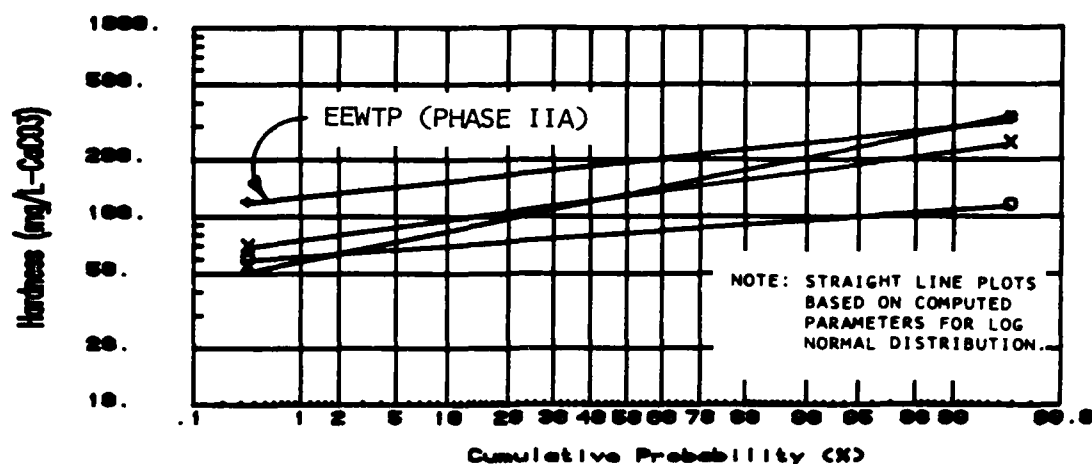
### SUMMARY

Among the major cations, anions, and nutrients monitored in EEWTP finished water of this study, only sodium and nitrate pose possible health concerns.

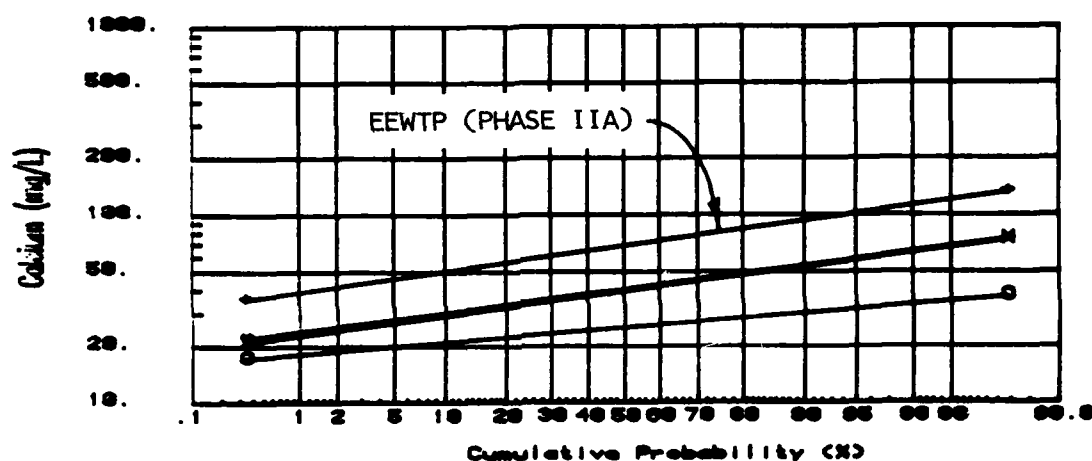
Sodium in EEWTP finished water is frequently present in concentrations exceeding the limit recommended by EPA. As a result, the finished water may not be acceptable for the very small portion of the population which must maintain extremely low intakes of dietary sodium because of hypertension or other special health conditions. At the levels of sodium observed in EEWTP finished water, the contribution of drinking water to total dietary sodium intake may become significant for this sensitive group. Substitution of distilled or bottled water for tap water may be necessary, depending on the relative contribution of the estuary supply to the consumer's drinking supply.

In 3.5 percent of samples taken during Phase IA and in 1.89 percent of samples taken during Phase IIA, the nitrate concentration exceeded the NIPDWR MCL of 10 mg/L as N. This primary standard is set to protect the infant portion of the population from methemoglobinemia, which results from conversion of nitrate to nitrite in the gastric tract and subsequent toxicity of nitrite. Therefore there is a likelihood that during periods when the concentration of nitrate is higher than 10 mg/L, portions of the population would be adversely affected. During this project, exceedance of the nitrate criteria occurred during periods when the Blue Plains nitrified effluent constituted more than fifty percent of the mix water. Under the projected estuary conditions outlined in Chapter 6, nitrate would be less of a problem than indicated by the EEWTP experience, with a maximum projected concentration of approximately 9 mg/L.-N. If, in fact, periods of high nitrate were to occur in the drought condition in the estuary, alternative unit processes would have to be considered (see Chapter 11), or finished water from the estuary plant would have to be blended with other local sources to reduce nitrate levels to below the standard.

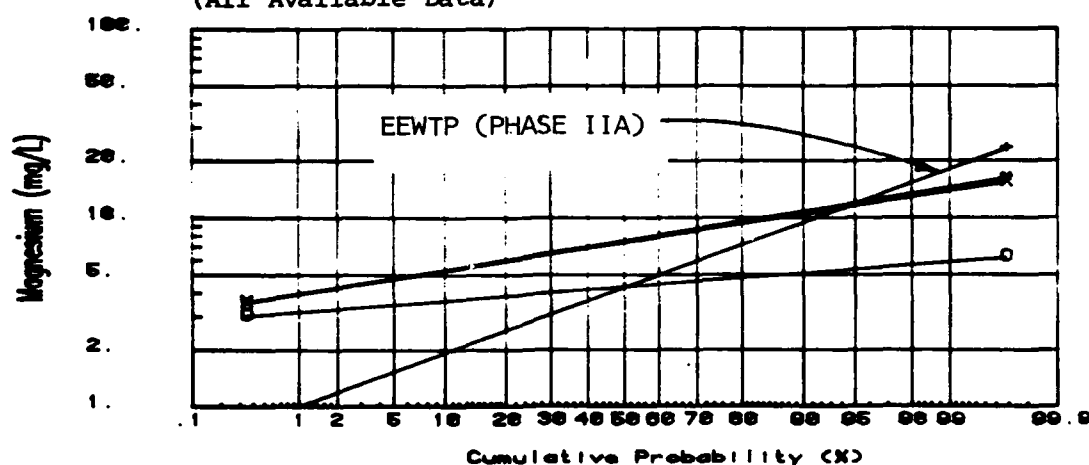
Concentrations of other mineral parameters are higher in the EEWTP finished water than in local plants. However, in general the other mineral species are present at levels which are not associated with health effects or aesthetic impact. In the case of hardness, it is possible that higher levels of hardness in EEWTP finished water may be beneficial to public health; domestic and industrial use, however, would have associated economic impact, particularly with respect to use of the lime phase finished water.



(a) Hardness in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)



(b) Calcium in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)



(c) Magnesium in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**HARDNESS, CALCIUM AND MAGNESIUM IN  
EEWTP FINISHED WATER (PHASE IIA) AND AT THREE LOCAL WTPs  
FIGURE 9. 3-12**

## SECTION 4

### TRACE METALS

#### INTRODUCTION

Investigators have recognized the importance of certain elements as essential in trace amounts for human nutrition and as toxic when consumed at higher concentrations. Some elements, such as lead, have been implicated as sources of chronic toxicity when present in the diet at low levels; others, such as arsenic, are believed to have carcinogenic effects when present in the diet. For many trace metals in drinking water, the known public health effect is negligible except at high concentrations, where acute toxic effects would occur.

The level at which public health effects occur varies with each trace element. Therefore, each element must be assessed individually. Parameters of special concern for health in drinking water have been identified in the toxicological literature. For some of the elements, the toxicological or carcinogenic effects have been well-documented and NIPDWR MCLs have been promulgated; for other elements, little is known and research is continuing. The basis for assessing the water quality of EEWTP finished water in this section is first to consider all metals regulated by NIPDWR MCLs or SMCLs, and to evaluate any which exceed those levels, and second to evaluate all others of health or aesthetic concern for which measured values exceed corresponding values in the local plants. For the parameters of particular concern, the importance of the levels observed are discussed. Information relating to health effects has been obtained through literature search, with Drinking Water and Health (NAS, 1977, 1980) as a primary source.

For each metal discussed, evaluation focuses on results obtained during Phases IA and IIA. These are discussed separately or together, as discrepancies between the results obtained during each phase warrant. Because of previously described operational changes in pH control which occurred through the latter part of Phase IA and through Phase IB, and which affected metals removal, results obtained during these time periods are also discussed for selected metals.

#### OVERVIEW

Median concentrations of trace metals measured in finished waters during the different phases of EEWTP operation, and in finished waters of local plants during both years of the sampling program, are shown in Table 9.4-1. For most of these metals the median values were at the part per billion ( $\mu\text{g/L}$ ) concentration or below. Many of the metals were below the analytical detection limit in the majority of samples.

TABLE 9.4-1  
SUMMARY OF TRACE METALS  
IN FINISHED WATERS

Parameter	Units	EEWTP					WTP3
		Median Values					
		Phase IA	Phase IB	Phase IIA	WTP1	WTP2	
Aluminum (ICP)	mg/L	0.020	0.150	0.020	0.070	0.190	0.07
Antimony (furnace AAS)	mg/L	<0.0003	-b	-b	<0.0003	<0.0003	<0.0003
Arsenic (furnace AAS)	mg/L	0.0002	0.0006	0.0003	0.0004	0.0003	0.0003
Barium (ICP)	mg/L	0.024	0.024	0.016	0.035	0.027	0.029
Beryllium (ICP)	mg/L	<0.0008	-b	-b	<0.0008	<0.0008	<0.0008
Boron (ICP)	mg/L	0.0442	0.0449	0.0431	0.0150	0.0273	0.0170
Cadmium (furnace AAS)	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (furnace AAS)	mg/L	0.0007	0.0011	0.0012	0.0021	0.0009	0.0017
Cobolt (furnace AAS)	mg/L	0.0005	-b	-b	0.0004	0.0002	0.0004
Copper (flame AAS)	mg/L	0.0023	<0.0013	<0.0012	0.0019	0.0032	0.0022
Iron (ICP)	mg/L	0.032	0.017	0.007	0.026	0.027	0.051
Lead (furnace AAS)	mg/L	0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Lithium (flame AAS)	mg/L	0.0046	0.0042	0.0058	0.0031	0.0007	0.0032
Manganese (ICP)	mg/L	0.0380	0.0059	<0.0010	0.0022	0.0088	0.0044
Mercury (cold vapor)	mg/L	<0.00027	<0.00027	<0.00027	-a	<0.00027	<0.00027
Molybdenum (ICP)	mg/L	<0.002	-b	-b	<0.002	<0.002	<0.002
Nickel (ICP)	mg/L	0.0028	0.0020	0.0013	0.0027	<0.0010	<0.0010
Selenium (furnace AAS)	mg/L	0.0007	<0.0002	0.0006	0.0005	0.0005	0.0005
Silver (furnace AAS)	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Thallium (furnace AAS)	mg/L	<0.0009	-b	-b	<0.0009	<0.0009	<0.0009
Tin (ICP)	mg/L	<0.0040	-b	-b	<0.0040	<0.0040	<0.0040
Titanium (ICP)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Vanadium (ICP)	mg/L	0.0024	<0.0020	0.0029	<0.0020	<0.0020	<0.0020
Zinc (flame AAS)	mg/L	0.0180	0.0077	0.0087	0.0026	0.0023	0.0023

a. Suspected sample contamination from sampling area; data not reported.

b. Sampling discontinued during this period.



## Trace Metals

Of the 24 metals analyzed, twelve have NIPDWR MCLs or SMCLs. All twelve are considered with respect to these limits and to corresponding levels in the local plants. Six have values warranting more detailed discussion: manganese, selenium, mercury, lead, zinc, and copper.

Among the remaining twelve metals, antimony, nickel, and thallium had higher values than found the local plants. Of these, however, only nickel was detected in over fifty percent of the samples. Because of concern with respect to health effects of these three metals, all are briefly discussed in the sections which follow. Boron, cobalt, lithium and vanadium also have values in excess of those observed at the local plants, but have no known health or aesthetic effects even at the highest concentrations measured and are not discussed further. Finally, aluminum, beryllium, molybdenum, tin and titanium have values less than at least one local plant and are not of significant health or aesthetic concern at these low concentrations. These are not discussed further, and are thus excluded from Table 9.4-2.

### PARAMETERS OF CONCERN FOR HEALTH OR AESTHETICS

Table 9.4-2 summarizes statistical information, including arithmetic and geometric means, for the fifteen metals of general health or aesthetic significance which are discussed below.<sup>1</sup> Among the trace metals measured in the finished waters, eight were identified as being of special concern during Phase IA: antimony, copper, lead, manganese, nickel, selenium, thallium, and zinc. These elements either had estimated geometric mean concentrations which were higher in the EEWTP finished water than in all local finished waters, or exhibited values in the distribution which were higher than at the local plants. Of these parameters, most were detected in at least fifty percent of the Phase IA finished water samples, with antimony and thallium as exceptions. Because higher levels were observed in EEWTP finished waters than in the local supplies, all eight of these metals are discussed in following sections. As discussed later, the concentrations in EEWTP finished waters were generally well below levels at which there is potential concern for health effects.

The only parameter recognized as being of special concern during the lime phase was zinc, which occurred at levels above those in local supplies.

Table 9.4-3 shows statistical comparisons of estimated geometric means in the EEWTP finished water with the local finished water having the highest levels of each metal. It also shows the number of degrees of freedom of the comparison, and the critical t-value at the 0.05 level of significance for the one-sided test. For antimony, manganese, nickel, and zinc, the geometric mean in EEWTP finished water in Phase IA is significantly above those for the local plants. For zinc, the lime phase finished water also has a geometric mean which is significantly above those in the local plants.

<sup>1</sup> Complete statistical summaries of monitoring data collected for all 24 metals is provided in Table H-6 of Appendix H.

## Trace Metals

TABLE 9.4-2  
COMPARISON OF FINISHED WATERS  
TRACE METALS  
OF CONCERN FOR HEALTH OR AESTHETICS

Parameter	Units	SEWTP				
		Phase IA	Phase IB	Phase IIA	WTP1	WTP2
Antimony Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	132/277	—1	—1	63/254	47/256
		0.00025/3.52	—	—	0.00009/5.16	0.00005/7.02
		0.00070/0.00181	—	—	0.00049/0.00158	0.00040/0.00102
		<0.0003/0.0010	—	—	<0.0003/0.0006	<0.0003/0.0006
Arsenic Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 0.05)	147/278	28/32	48/55	264/343	245/343
		0.00020/4.65	0.00050/1.85	0.00037/1.82	0.00039/2.81	0.00032/2.64
		0.00094/0.00328	0.00058/0.00036	0.00044/0.00030	0.00079/0.00206	0.00057/0.00115
		0.0002/0.0009	0.0005/0.0010	0.0003/0.0009	0.0004/0.0011	0.0003/0.0009
Barium Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 1.0)	265/276	32/32	55/55	340/340	339/339
		0.022/1.78	0.025/1.28	0.017/1.31	0.031/1.88	0.025/1.56
		0.0094/0.008	0.025/0.006	0.017/0.005	0.034/0.011	0.027/1.007
		0.024/0.032	0.024/0.031	0.016/0.024	0.035/0.047	0.027/0.034
Cadmium (ICAP)2 Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 0.01)	33/252	—	—	21/235	23/236
		—3	—	—	—	—
		<0.0008	—	—	<0.0008	<0.0008/0.0143
		<0.0008/0.0009	—	—	<0.0008/0.0008	<0.0008/0.0008
Cadmium (furnace AAS)4 Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 0.01)	2/26	6/32	2/55	9/107	6/105
		—	0.0004/6.62	—	—	—
		<0.0002	0.00022/0.00029	<0.0002	<0.0002	<0.00020
		<0.0002/0.0002	<0.0002/0.0006	<0.0002/0.0002	<0.0002/0.0002	<0.0002/0.0002
Chromium (ICAP)2 Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 0.05)	6/252	—	—	62/234	9/237
		—	—	—	0.0020/1.87	—
		<0.003	—	—	<0.003	<0.003
		<0.003/0.003	—	—	<0.003/0.005	<0.003/0.003
Chromium (furnace AAS)4 Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L (MCL = 0.05)	17/26	29/32	53/55	98/108	88/105
		0.00047/4.30	0.00095/2.42	0.0012/2.50	0.0017/2.79	0.00077/2.83
		0.0010/0.00096	0.0013/0.0010	0.0018/0.0016	0.0025/0.0021	0.0012/0.0011
		0.0007/0.0024	0.0009/0.0025	0.0012/0.0038	0.0021/0.0044	0.0009/0.0025
Copper Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	53/251	—	—	—	—
		0.00008/5.23	—	—	—	—
		0.00043/0.00144	—	—	—	—
		<0.0003/0.0005	—	—	—	—
Lead Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	226/332	—	—	—	—
		0.00030/2.62	—	—	—	—
		0.00054/0.00136	—	—	—	—
		0.0003/0.0009	—	—	—	—
Manganese Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	330/330	—	—	—	—
		0.026/1.69	—	—	—	—
		0.029/0.010	—	—	—	—
		0.029/0.041	—	—	—	—
Mercury Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	19/229	—	—	—	—
		—	—	—	—	—
		<0.0008	—	—	—	—
		<0.0008/0.0008	—	—	—	—
Nickel Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	9/102	—	—	—	—
		—	—	—	—	—
		0.00020/0.00073	—	—	—	—
		<0.0002/0.0002	—	—	—	—
Silver Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	20/229	—	—	—	—
		—	—	—	—	—
		<0.003	—	—	—	—
		<0.003/0.003	—	—	—	—
Zinc Number Det'd/Number Geom. Mean/Spread Factor Arith. Mean/Std. Dev. Median/90 Percentile	mg/L	94/102	—	—	—	—
		0.0016/2.93	—	—	—	—
		0.0026/0.0032	—	—	—	—
		0.0017/0.0025	—	—	—	—

TABLE 9.4-2 (Continued)

COMPARISON OF FINISHED WATERS  
TRACE METALS  
OF CONCERN FOR HEALTH OR AESTHETICS

Parameter	Units	EEWTP					WTP2	WTP3
		Phase IA	Phase IB	Phase IIA	WTP1			
Copper (ICAP)2								
Number Det'd/Number	mg/L	174/252	—	—	178/235	218/238	171/230	
Geom. Mean/Spread Factor	(SMCL = 1.0)	0.0016/3.21	—	—	0.0019/2.63	0.0047/2.40	0.0019/2.90	
Arith. Mean/Std. Dev.		0.0033/0.0088	—	—	0.0028/0.0027	0.0063/0.0041	0.0032/0.0037	
Median/90 Percentile		0.0019/0.0060	—	—	0.0024/0.0058	0.0056/0.0115	0.0026/0.0061	
Copper (flame AAS)4								
Number Det'd/Number	mg/L	20/26	21/32	22/55	79/108	92/105	80/103	
Geom. Mean/Spread Factor	(SMCL = 1.0)	0.0025/2.88	0.0014/1.50	0.00096/2.55	0.0019/2.08	0.0031/2.12	0.0021/2.29	
Arith. Mean/Std. Dev.		0.0044/0.0060	0.0014/0.0074	0.0015/0.0014	0.0024/0.0022	0.0040/0.0031	0.0038/0.0129	
Median/90 Percentile		0.0023/0.0086	0.0013/0.0024	<0.0012/0.0031	0.0019/.0046	0.0032/0.0081	0.0022/0.0048	
Iron								
Number Det'd/Number	mg/L	239/278	28/32	38/55	292/341	304/340	319/333	
Geom. Mean/Spread Factor	(SMCL = 0.3)	0.024/4.34	0.017/3.34	0.0071/4.05	0.020/3.89	0.023/3.28	0.047/2.95	
Arith. Mean/Std. Dev.		0.098/0.457	0.035/0.064	0.016/0.021	0.053/0.197	0.042/0.072	0.083/0.157	
Median/90 Percentile		0.032/0.084	0.017/0.056	0.007/0.038	0.026/0.070	0.027/0.092	0.051/0.140	
Lead								
Number Det'd/Number	mg/L	152/278	7/32	13/54	166/342	164/341	162/331	
Geom. Mean/Spread Factor	(MCL = .05)	0.00033/3.74	0.00016/2.24	0.00012/3.71	0.00028/3.61	0.00028/3.77	0.00028/3.97	
Arith. Mean/Std. Dev.		0.00092/0.00247	0.00023/0.00017	0.00031/0.00036	0.00068/0.00144	0.00067/0.00138	0.00080/0.00231	
Median/90 Percentile		0.0003/0.0016	<0.003/0.0006	<0.0003/0.0007	<0.0003/0.0012	<0.0003/0.0016	<0.0003/0.0015	
Manganese								
Number Det'd/Number	mg/L	278/278	27/32	17/55	269/342	330/342	312/332	
Geom. Mean/Spread Factor	(SMCL = .05)	0.0304/2.99	0.0046/3.63	0.00039/7.12	0.0022/2.53	0.0075/2.49	0.0051/3.21	
Arith. Mean/Std. Dev.		0.0518/0.0726	0.0092/0.0123	0.0021/0.0037	0.0033/0.0040	0.0107/0.0104	0.0120/0.0332	
Median/90 Percentile		0.0380/0.1093	0.0059/0.0203	<0.0010/0.0081	0.0022/0.0069	0.0088/0.0200	0.0044/0.0200	
Mercury								
Number Det'd/Number	mg/L	103/278	11/32	10/55	—5	84/339	102/329	
Geom. Mean/Spread Factor	(MCL = .002)	0.00020/2.71	0.0020/2.17	0.00009/3.32	—	0.00014/2.78	0.00015/3.20	
Arith. Mean/Std. Dev.		0.00032/0.00041	<0.00027	<0.00027	—	<0.00027	0.00032/0.00052	
Median/90 Percentile		<0.00027/0.0007	<0.00027/0.0005	<0.00027/0.0004	—	<0.00027/0.0005	<0.00027/0.0006	
Nickel								
Number Det'd/Number	mg/L	217/275	18/32	30/55	232/340	81/339	125/330	
Geom. Mean/Spread Factor		0.0024/2.29	0.0015/4.20	0.0012/2.40	0.0020/2.83	0.00036/4.47	0.00072/3.51	
Arith. Mean/Std. Dev.		0.0032/0.0027	0.0034/0.0048	0.0017/0.0014	0.0031/0.0028	0.0011/0.0016	0.0015/0.0019	
Median/90 Percentile		0.0028/0.0058	0.0020/0.0084	0.0013/0.0039	0.0027/0.0061	<0.0010/0.0028	<0.0010/0.0035	

## Trace Metals

TABLE 9.4-2 (Continued)  
COMPARISON OF FINISHED WATERS  
TRACE METALS  
OF CONCERN FOR HEALTH OR AESTHETICS

Parameter	Units	EEWTP					WTP3
		Phase IA	Phase IB	Phase IIA	WTP1	WTP2	
<b>Selenium</b>							
Number Det'd/Number	mg/L	193/278	7/32	391/55	229/343	224/343	242/331
Geom. Mean/Spread Factor	(MCL = .01)	0.00051/4.33	0.00006/4.31	0.00046/2.97	0.00044/4.45	0.00042/4.59	0.00050/3.75
Arith. Mean/Std. Dev.		0.0012/0.0014	0.00021/0.00035	0.00072/0.00058	0.0011/0.0015	0.0012/0.0026	0.0011/0.0014
Median/90 Percentile		0.0007/0.0026	<0.0002/0.0004	0.0006/0.0015	0.0005/0.0027	0.0005/0.0025	0.0005/0.0026
<b>Silver (flame AAS)<sup>2</sup></b>							
Number Det'd/Number	mg/L	10/252	—	—	7/235	15/238	15/229
Geom. Mean/Spread Factor	(MCL = .05)	—	—	—	—	—	—
Arith. Mean/Std. Dev.		<0.0008	—	—	<0.0008	<0.0008	<0.0008
Median/90 Percentile		<0.0008/<0.0008	—	—	<0.0008/<0.0008	<0.0008/<0.0008	<0.0008/<0.0008
<b>Silver (furnace AAS)<sup>3</sup></b>							
Number Det'd/Number	mg/L	0/26	2/32	2/55	8/108	4/105	14/102
Geom. Mean/Spread Factor	(MCL = .05)	—	—	—	—	—	—
Arith. Mean/Std. Dev.		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.00019/0.00038
Median/90 Percentile		<0.0002/<0.0002	<0.0002/<0.0002	<0.0002/<0.0002	<0.0002/<0.0002	<0.0002/<0.0002	<0.0002/0.0003
<b>Thallium</b>							
Number Det'd/Number	mg/L	N = 277	— <sup>2</sup>	— <sup>2</sup>	1/255	0/256	2/251
Geom. Mean/Spread Factor		—	—	—	—	—	—
Arith. Mean/Std. Dev.		<0.009	—	—	<0.0009	<0.0009	<0.0009
Median/90 Percentile		<0.0009/<0.0009	—	—	<0.0009/<0.0009	<0.0009/<0.0009	<0.0009/<0.0009
<b>Zinc (ICAP)<sup>2</sup></b>							
Number Det'd/Number	mg/L	251/251	—	—	169/234	151/238	155/228
Geom. Mean/Spread Factor	(SMCL = 5)	0.0589/1.58	—	—	0.0038/2.92	0.0030/2.95	0.0033/2.85
Arith. Mean/Std. Dev.		0.0650/0.0276	—	—	0.0068/0.0101	0.0052/0.0064	0.0059/0.0099
Median/90 Percentile		0.0624/0.1007	—	—	0.0038/0.0141	0.0035/0.0121	0.0036/0.0106
<b>Zinc (flame AAS)<sup>3</sup></b>							
Number Det'd/Number	mg/L	26/26	32/32	55/55	90/108	75/105	71/103
Geom. Mean/Spread Factor	(SMCL = 5)	0.0218/2.04	0.0093/2.49	0.0083/1.85	0.0030/3.66	0.0021/2.79	0.0022/3.14
Arith. Mean/Std. Dev.		0.0303/0.346	0.0166/0.0294	0.0100/0.0068	0.0090/0.0190	0.0037/0.0058	0.0048/0.0127
Median/90 Percentile		0.0180/0.0474	0.0077/0.0286	0.0087/0.0180	0.0026/0.0160	0.0023/0.0067	0.0023/0.0080

1. Monitoring terminated on 16 March 1982 at all sites.
2. Analysis by this method terminated on 1 December 1981.
3. Geometric Mean not calculated if less than fifteen percent of samples were above the detection limit.
4. Analysis by this method initiated on 1 December 1981.
5. Suspected sample contamination from sampling area; data not reported.

## Trace Metals

TABLE 9.4-3  
APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES  
IN GEOMETRIC MEANS FOR TRACE METALS IN FINISHED WATERS<sup>1</sup>

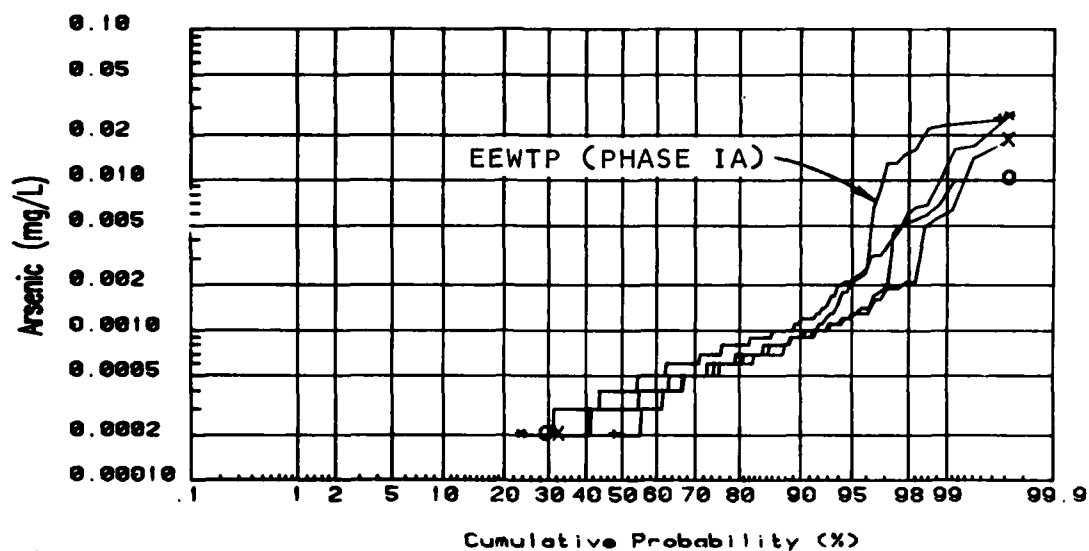
Constituent	Highest Geometric Mean at Local WTP	Phase of EEWTP Operation	Geometric Mean at EEWTP	Number of Degrees of Freedom	T	t-statistic for 0.05 Significance Level	Significant Difference
Antimony	0.00009	Alum-IA	0.00025	55.6	8.00	1.64	WTP1 < EEWTP
		Alum-IB <sup>2</sup>	—	—	—	—	—
		Lime-IIA <sup>2</sup>	—	—	—	—	—
Arsenic	0.00039	Alum-IA	0.00020	303.8	-6.20	1.64	EEWTP < WTP1
		Alum-IB	0.00050	46.9	2.03	1.68	WTP1 < EEWTP
		Lime-IIA	0.00037	99.3	-0.54	1.66	No Signif. Diff.
Barium	0.03070	Alum-IA	0.0215	317.5	-6.79	1.64	EEWTP < WTP1
		Alum-IB	0.0246	10.5	-3.99	1.67	EEWTP < WTP1
		Lime-IIA	0.0166	136.3	-12.30	1.66	EEWTP < WTP1
Cadmium <sup>3</sup>							
Chromium	0.0017	Alum-IA	0.00047	29.6	-4.25	1.70	EEWTP < WTP1
		Alum-IB	0.00095	47.5	-3.15	1.68	EEWTP < WTP1
		Lime-IIA	0.00123	78.4	-2.05	1.67	EEWTP < WTP1
Copper	0.00306	Alum-IA	0.00249	29.7	-0.94	1.70	No Signif. Diff.
		Alum-IB	0.00137	66.6	-7.84	1.67	EEWTP < WTP2
		Lime-IIA	0.00096	68.5	-7.94	1.67	EEWTP < WTP2
Iron	0.0468	Alum-IA	0.0244	303.5	-6.14	1.64	EEWTP < WTP3
		Alum-IB	0.0167	35.4	-4.66	1.68	EEWTP < WTP3
		Lime-IIA	0.0071	63.1	-9.54	1.67	EEWTP < WTP3
Lead	0.00028	Alum-IA	0.00033	313.7	1.50	1.64	No Signif. Diff.
		Alum-IB	0.00016	48.1	-3.47	1.68	EEWTP < WTP3
		Lime-IIA	0.00012	69.5	-4.37	1.67	EEWTP < WTP3
Manganese	0.00747	Alum-IA	0.03040	311.6	17.08	1.64	WTP2 < EEWTP
		Alum-IB	0.00456	33.7	-2.12	1.70	EEWTP < WTP2
		Lime-IIA	0.00039	57.2	-10.97	1.67	EEWTP < WTP2
Mercury	0.00015	Alum-IA	0.00020	315.4	3.28	1.64	WTP3 < EEWTP
		Alum-IB	0.00020	44.1	1.90	1.68	WTP3 < EEWTP
		Lime-IIA	0.00009	68.5	-2.94	1.66	EEWTP < WTP3

TABLE 9.4-3 (Continued)

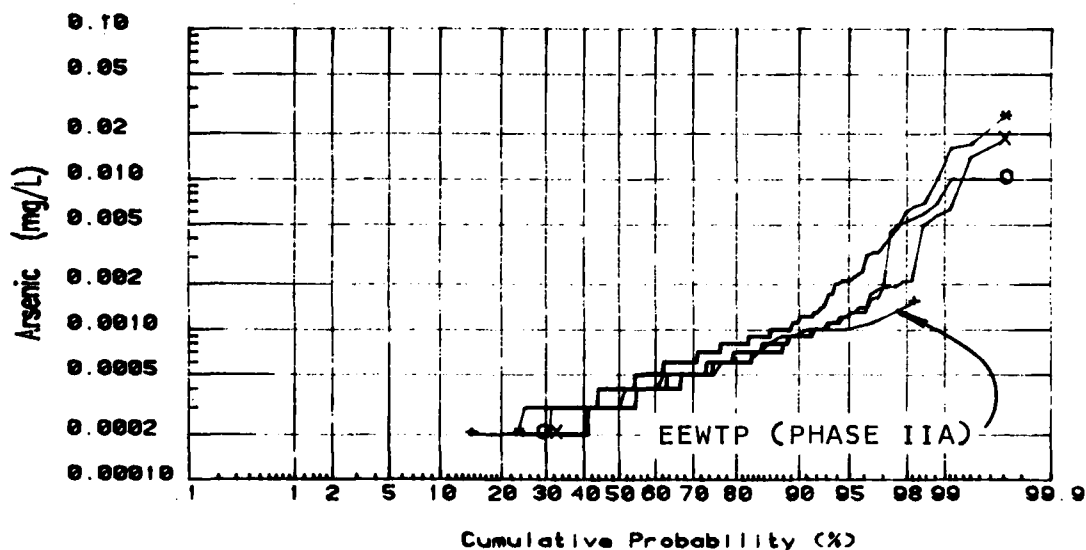
APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES  
IN GEOMETRIC MEANS FOR TRACE METALS IN FINISHED WATERS<sup>1</sup>

Constituent	Highest Geometric Mean at Local WTP	Phase of EEWTP Operation	Geometric Mean at EEWTP	Number of Degrees of Freedom	T	t-statistic for 0.05 Significance Level	Significant Difference
Nickel	0.00204	Alum-IA	0.00237	324.1	1.99	1.64	WTP1 < EEWTP
		Alum-IB	0.00145	33.8	-1.31	1.70	No Signif. Diff.
		Lime-IIA	0.00121	75.4	-3.99	1.67	EEWTP < WTP1
Selenium	0.0005	Alum-IA	0.00051	309.1	0.17	1.64	No Signif. Diff.
		Alum-IB	0.00006	35.6	-7.90	1.68	EEWTP < WTP1
		Lime-IIA	0.00046	76.8	-0.51	1.66	No Signif. Diff.
Silver <sup>3</sup>							
Zinc	0.0030	Alum-IA	0.02183	53.1	10.59	1.67	WTP1 < EEWTP
		Alum-IB	0.00926	54.6	5.53	1.67	WTP1 < EEWTP
		Lime-IIA	0.0083	98.0	6.79	1.66	WTP1 < EEWTP

1. Hypothesis testing as described in Appendix B. One sided t-test at 0.05 significance level.
2. Insufficient quantified data for determination of geometric mean in EEWTP finished water.
3. Insufficient quantified data for determination of geometric mean in EEWTP finished water during all three phases.

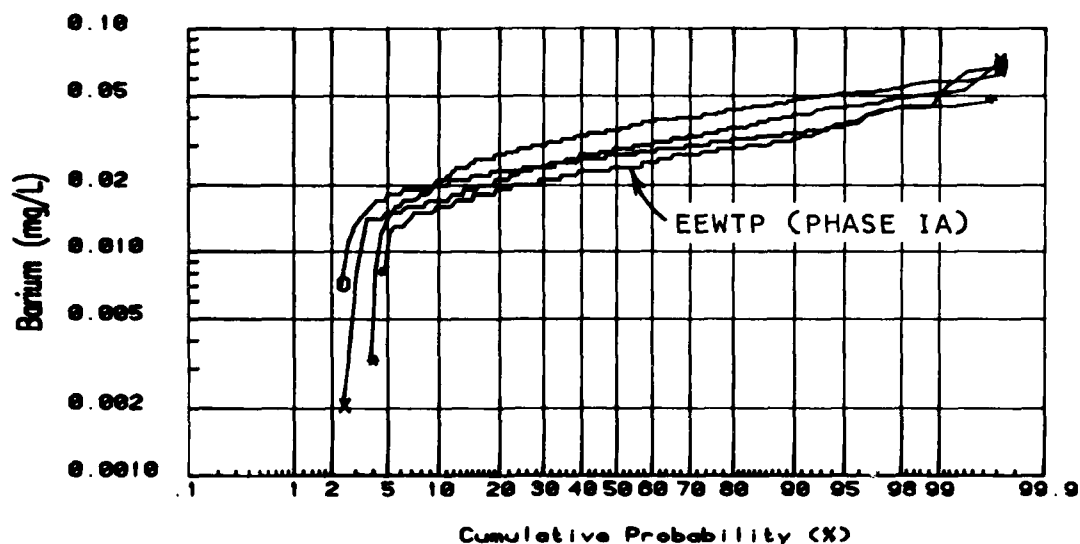


(a) Arsenic in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)

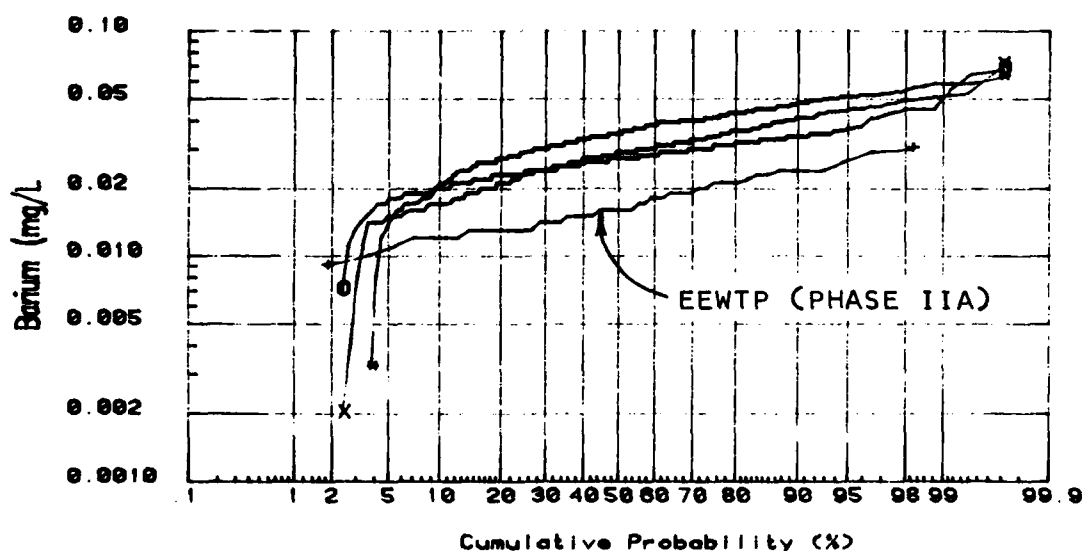


(b) Arsenic in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**ARSENIC IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-1**



(a) Barium in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Barium in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**BARIUM IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-2**



## TRACE METALS WITH PRIMARY STANDARDS

Of all the metals with an interim primary MCL, only mercury ever exceeded the MCL during daily sampling. Because of the importance of the metals with primary standards, it is useful to compare EEWTP results with the monitored local finished waters. All eight metals are discussed individually in the following sections.

### Arsenic

Arsenic has an NIPDWR MCL of 0.05 mg/L. All values measured at the EEWTP during two years of monitoring (both alum and lime phases) are well below this MCL. The EEWTP results are also acceptable in comparison to the local plants. Figures 9.4-1(a) and 9.4-1(b) show the complete probability distributions for samples drawn from EEWTP finished water alum and lime phases, respectively, relative to distributions from the local finished waters during the two years of monitoring. At the higher percentiles in the Phase IA operations, a few of the EEWTP values exceed those of the local plants. Because of the skewed distribution at the higher percentile during Phase IA (Figure 4.4-1(a)), the arithmetic mean level during this period is higher than at the local plants, as shown in Table 9.4-2. Concentrations remain below the MCL, however, and are not significant from a health standpoint. Tables 9.4-2 and 9.4-3 show that the estimated geometric mean concentrations of arsenic in the EEWTP finished waters are significantly lower than that of WTP1.

### Barium

Barium has acute toxic effects at high intake levels, and can be fatal at doses above 500 mg. (NAS, 1977). The NIPDWR MCL for barium is set at 1 mg/L, to provide an adequate margin of safety below the levels at which acute effects can occur.

All concentrations of barium measured during the EEWTP operation are much less than this level. The distributions of barium values in the finished water from the EEWTP and the three local plants are compared in Figures 9.4-2(a) and 9.4-2(b). As shown, the values from EEWTP are consistently lower than those at the local plants. Finally, Tables 9.4-2 and 9.4-3 show that the estimated geometric mean levels for the EEWTP during both Phase IA and Phase IIA are significantly below the geometric mean for WTP1 during the two years of monitoring. Thus levels of barium do not pose a concern for public health.

## Trace Metals

### Cadmium

The NIPDWR MCL for cadmium is established at 0.010 mg/L. The NAS estimates average daily intake of cadmium from air, water, food and cigarettes to range between 0.040 and 0.190 mg/day. The contribution from water having a cadmium concentration of 0.010 mg/L would be between 5 and 25 percent of this normal intake. Cadmium does not become toxic until intake levels are much higher. Nearly all EEWTP finished water levels during both Phase IA and IB were below the analytical detection limit of 0.0002 mg/L. The few data above the detection limit suggest that the levels in the EEWTP finished water were below those in the local plants, as shown in Figure 9.4-3. In any case, all values were far below the NIPDWR MCL, so observed values do not pose a concern for public health.

### Chromium

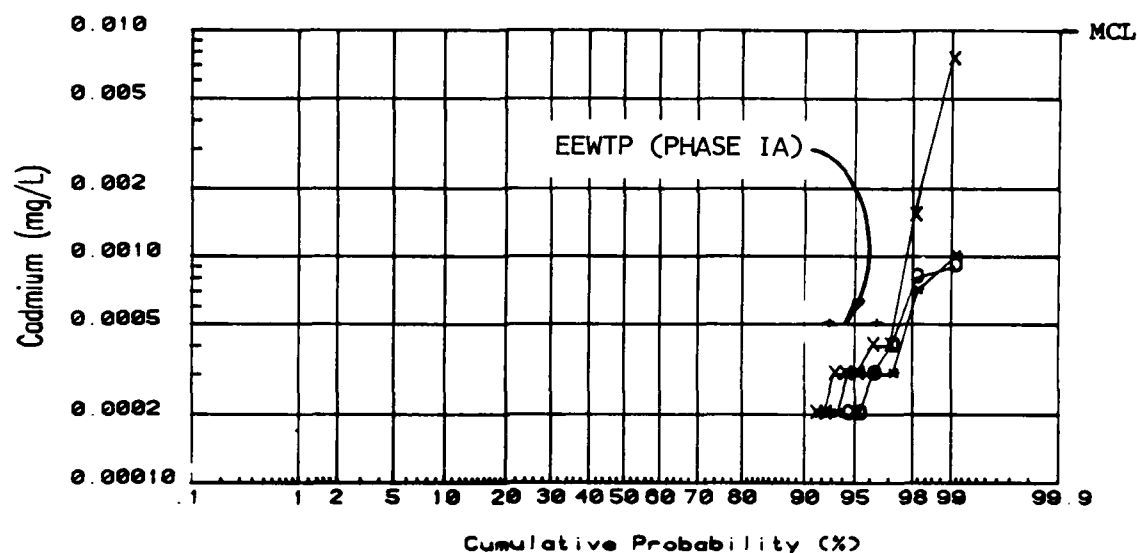
The NIPDWR MCL for chromium is 0.05 mg/L, which is below the no-observed-adverse-effect level. Chronic toxicity from chromium can be observed when drinking water contains concentrations of hexavalent chromium of 5 mg/L or more.

All values observed at the EEWTP were below the MCL, and the estimated geometric means from Phases IA and IIA were significantly below that in a local plant (Table 9.4-3). As Figures 9.4-4(a) and (b) show, even at the highest percentiles, the values for chromium in the EEWTP finished water were below two of the local plants.

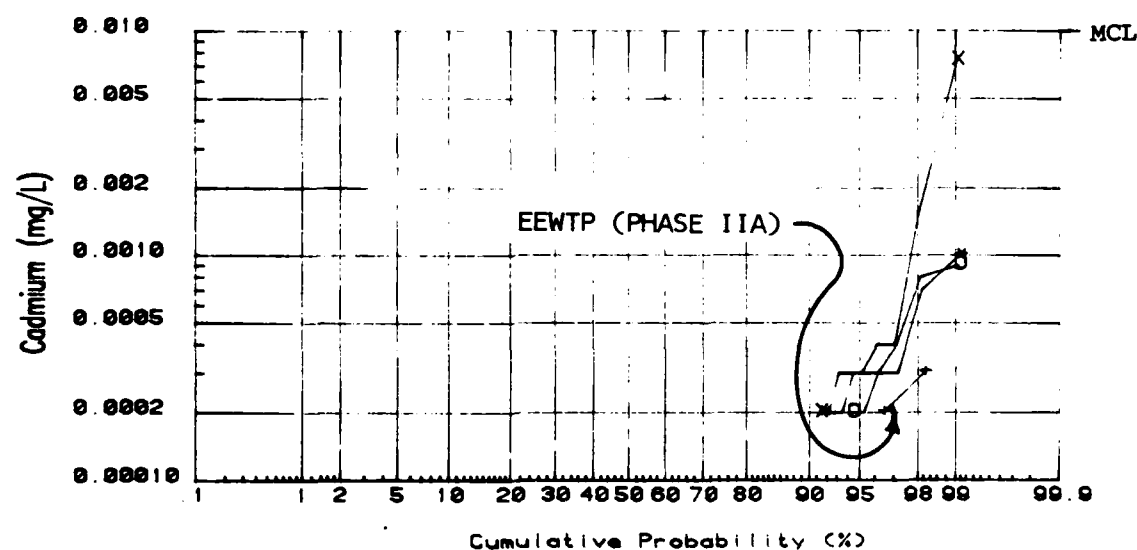
### Lead

The health significance of lead relates to chronic toxicity at low levels, rather than to acute toxicity, which only occurs at extremely high doses. Environmental exposure to lead takes place through inhalation of particulates from exhaust from internal combustion engines fired by leaded fuels, paints with lead additives, dietary lead as from cans with leaded solder, and drinking water. Effects of chronic exposure can include decreased heme synthesis in red blood cells, kidney insufficiency, and decreased mental development in small children. According to the National Academy of Sciences, there is not enough detailed information in the toxicological literature on the dose-response relationship for lead health effects to determine an appropriate maximum contaminant level. Despite the NAS findings, at the present time the federal primary standard of 0.05 mg/L remains the principal guideline for health effects of lead in drinking water. As is discussed below, lead concentrations in EEWTP finished water never exceeded this MCL. However, due to lower ambient pH during initial months of Phase IA operations (16 March 1981 to 1 October 1981), lead concentrations were higher than during the remainder of the project. The significance of these early results as well as those from subsequent phases are discussed below.

Alum Phase. Probability distributions for lead in the EEWTP Phase IA treated water and at the local plants are shown in Figure 9.4-5(a). Approximately 55

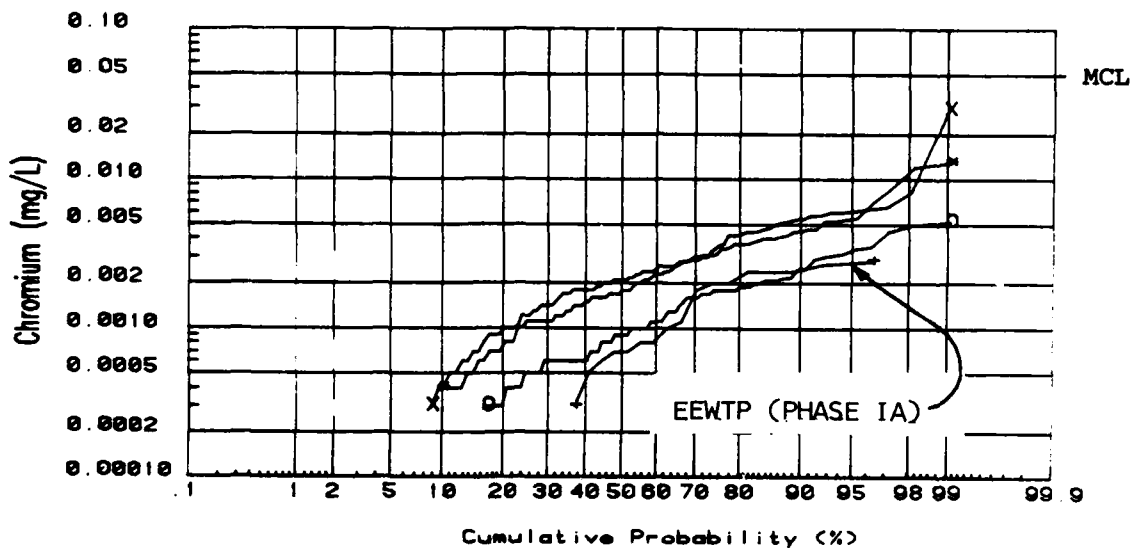


(a) Cadmium in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)

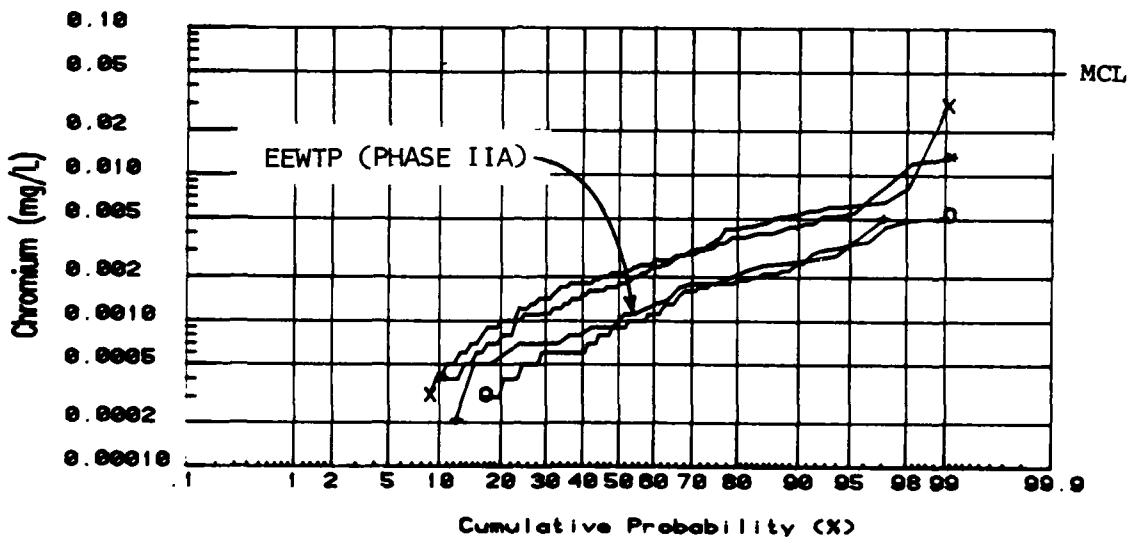


(b) Cadmium in EEWTP Finished Water (16 July 1981 to 1 February 1982 - Phase IIA) and at Three Local WTP's (All Available Data)

**CADMIUM IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-3**



(a) Chromium in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)



(b) Chromium in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**CHROMIUM IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-4**

## Trace Metals

percent of the samples are above the detection limit of 0.003 mg/L. As the figure suggests, the geometric mean concentrations of EEWTP Phase IA finished water and WTP 3 are not significantly different at the 0.05 significance level (Table 9.4-3). The plot shows graphically that the probability distributions are nearly indistinguishable, except at high percentiles where the lead values in the EEWTP are slightly higher. The higher lead levels at the higher percentiles of the EEWTP distribution cause the arithmetic mean to be estimated at a value of 0.00092 mg/L, above that for any local plant. Thus, increased chronic effect might be anticipated, although the lead is still well below the MCL.

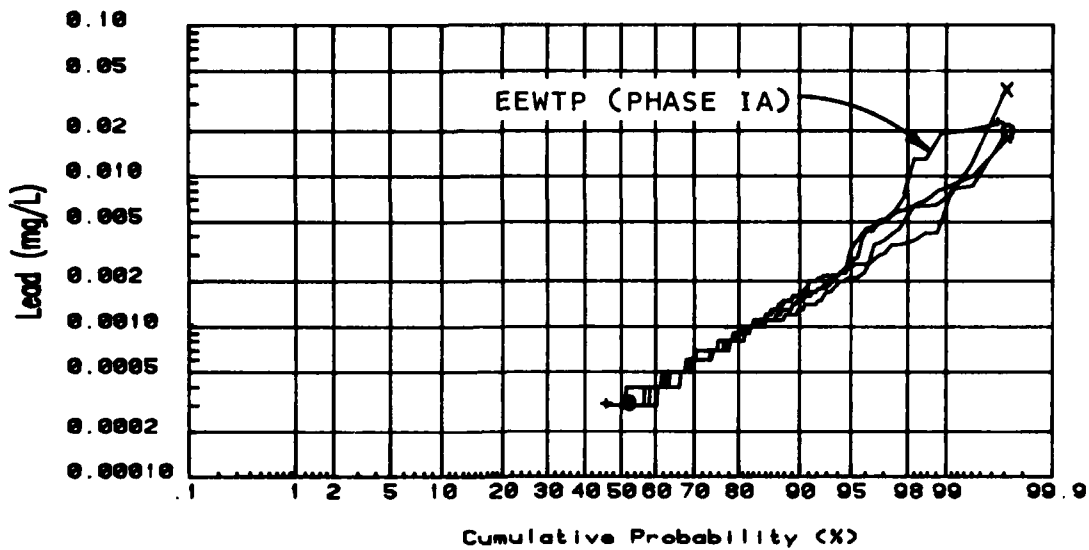
A major factor accounting for the observed concentrations of lead in the Phase IA finished water is the fact that the pH in the EEWTP processes during this period was lower than was true for subsequent phases, and was in fact below 6.5 in finished water in a substantial percent of the samples in Phase IA. Low pH levels tend to raise the solubility of lead and diminish the effectiveness of removal of lead through treatment. Table 9.4-4 below shows the arithmetic mean lead levels as calculated for the different phases of operation. In contrast to the data for all of Phase IA, the EEWTP finished water has levels clearly below those of the local plants during later periods when pH was controlled at higher levels. This indicates that appropriate operation of treatment processes can result in lowered lead levels in finished water. Despite the fact that the NIPDWR MCL was not exceeded even during periods of low pH, the chronic health effects associated with lead, and the demonstrably higher levels which occur when pH is not controlled, suggest that any full-scale plant should be designed and operated so as to maintain appropriate pH levels.

**TABLE 9.4-4**  
**AVERAGE LEAD CONCENTRATIONS IN EEWTP FINISHED WATER**  
**COMPARED TO THREE LOCAL FINISHED WATERS**  
**(MCL = 0.05 mg/L)**

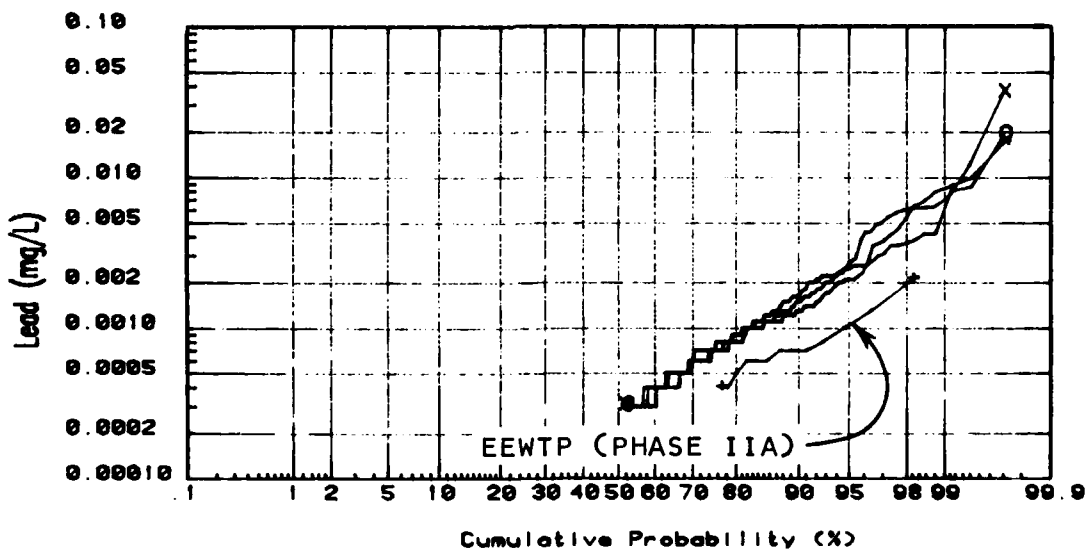
	Phase IA	Phase IA After 1 Dec 1981	Phase IB	WTP1	WTP2	WTP3
Number of Samples	278	26	32	342	341	331
Number Detected	152	9	7	166	164	162
Arithmetic Mean <sup>1</sup>	0.00092	0.00032	0.00023	0.0006	0.00067	0.00080
Standard Deviation	0.00247	0.00036	0.0036	0.0014	0.0014	0.0023

1. Concentrations in mg/L

Lime Phase. During lime phase operations, EEWTP finished water pH ranged from 6.9-7.8 pH units and lead concentrations remained low. Less than 25



(a) Lead in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Lead in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**LEAD IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-5**

percent of the samples taken during Phase IIA were above the detection limit (Table 9.4-2), and, as Figure 9.4-6(b) illustrates, all values were below those observed at the local WTPs. These results suggest that there are no relative adverse health effects associated with lead in the lime phase EEWTP finished water.

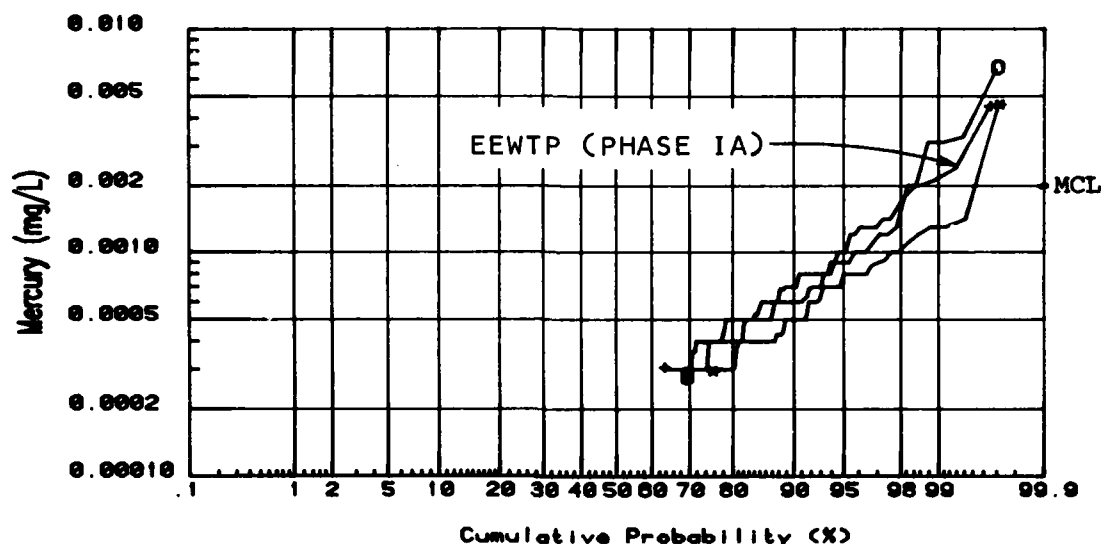
### Mercury

The NIPDWR MCL for mercury is established at 0.002 mg/L. The principal health effect of dietary mercury results from organically bound forms of the metal such as methylmercury, rather than from the metallic form or inorganic forms. The Minamata Bay, Japan, episode brought the risks of methylmercury toxicity to public attention. In that case, ingestion of fish and shellfish in which methylmercury had been concentrated through the food chain resulted in intoxication and death among the local population. There was no evidence for a drinking water route for the mercury. Toxicological evidence suggests that the mercury present in drinking water may be predominantly in inorganic form, and not a significant contributor to methylmercury intake. The inorganic forms of mercury have toxic effects only at much higher concentrations than the federal MCL, or those observed in finished waters.

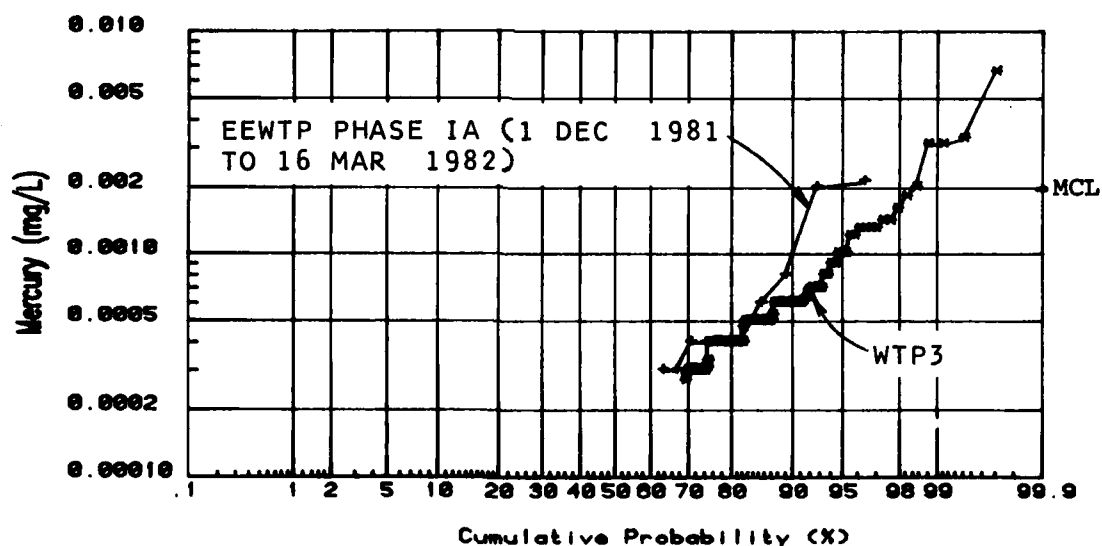
Alum Phase. Data for Phase IA EEWTP finished water mercury levels are presented in Figure 9.4-6(a), along with data for two of the local plants. During this phase, the mercury concentration in EEWTP finished water exceeded the primary drinking water standard three times out of 279 samples, or in 1.08 percent of the samples. A 95 percent confidence interval based on the binomial distribution suggests that the mercury concentration would exceed the MCL between 0.2 percent and 3.1 percent of the time, under conditions corresponding to Phase IA. Figure 9.4-7(a) suggests, and Table 9.4-3 confirms that the estimated geometric mean concentration of these mercury concentrations is not significantly different from the geometric mean estimated for the local plant with the next highest level, however. Because mercury in the diet can produce chronic health effects, further examination of the data is merited.

Data from the period of Phase IA between 1 December 1981 and 16 March 1982, when pH control tended to keep the value of pH above 6.5 are shown in Figure 9.4-7(b). Data from Phase IB, when pH control remained in effect and ozonation was used instead of chlorination in the process train are shown in Figure 9.4-8(a). In both plots the data from WTP3 over the full period of the study are shown for comparison. During the period from December through March in Phase IA, one of 26, or 3.8 percent, of the samples had mercury concentrations above the MCL. During Phase IB, the NIPDWR MCL was never exceeded. The distributions of concentrations during these periods, however, are not noticeably different from those observed during the first part of Phase IA.

It should be noted that the mercury concentrations found in EEWTP finished water would not be associated with acute toxicity. Overall chronic effect of



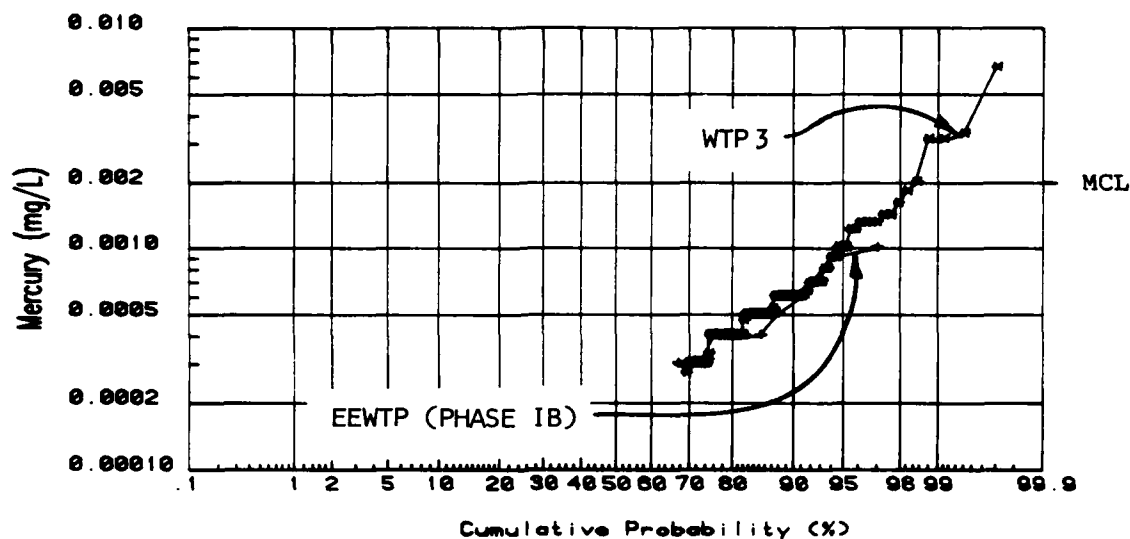
(a) Mercury in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at two local WTPs (All Available Data)



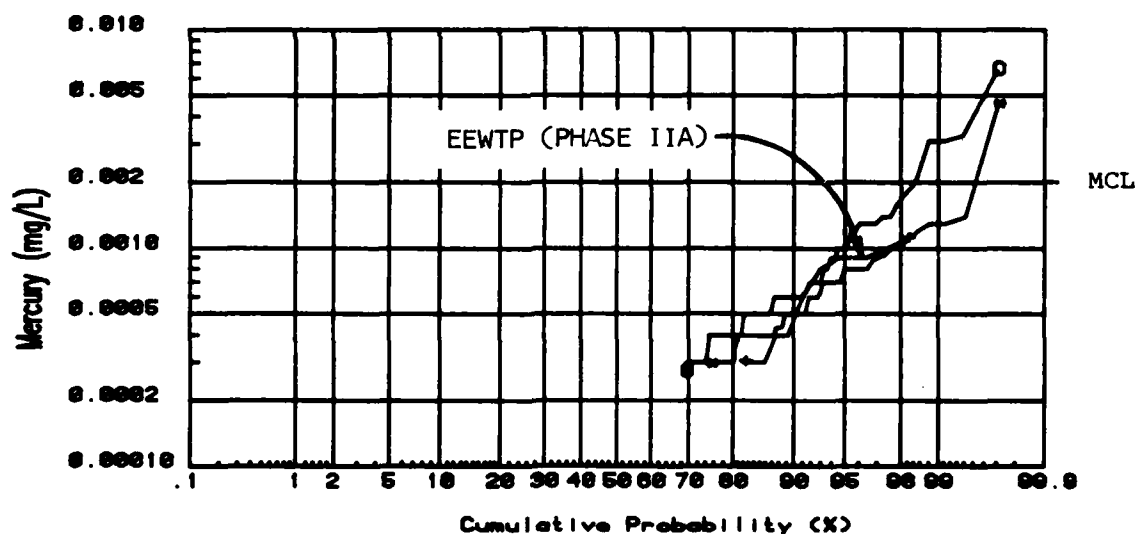
(b) Mercury in EEWTP finished water (1 December 1981 to 16 March 1982 - Phase IA after pH control) and WTP3 finished water (all available data)

**MERCURY IN EEWTP FINISHED WATER  
COMPARED TO RESULTS FROM LOCAL WTPs  
(PHASE IA)  
FIGURE 9. 4-6**





(a) Mercury in EEWTP Finished Water (16 March 1982 to 6 July 1982 - Phase IB) and WTP 3 Finished Water (All Available Data)



(b) Mercury in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Two Local WTP's (All Available Data)

# MERCURY IN EEWTP FINISHED WATER AND AT TWO LOCAL WTPs FIGURE 9. 4-7

## Trace Metals

use of this finished water for drinking water supply would roughly correspond to the estimated arithmetic mean concentration of 0.0032 mg/L, which is approximately the same as in the local finished waters and well below the MCL. It should also be noted that the local supplies also exceeded the MCL in a small number of samples. The MCL, however, is based on annual sampling rather than daily sampling for trace metals; values above the MCL would probably not be observed with the federally required monitoring and are of debatable significance in light of the overall low concentrations observed.

**Lime Phase.** During the lime phase, EEWTP finished water levels of mercury were lower than the levels in one local treatment plant at most of the percentiles of the distribution, as shown in Figure 9.4-7(b). The Phase IIA estimated geometric mean was lower than that observed at a local MWA plant, and all Phase IIA samples were below the NIPDWR MCL of 0.002. Mercury concentrations were, therefore, not at levels of concern during this phase.

### Selenium

The NIPDWR MCL for selenium is 0.01 mg/L. According to surveys reviewed by the NAS, this level is rarely exceeded in raw or finished water supplies; exceptions are groundwaters drawn from areas rich in seleniferous shales.

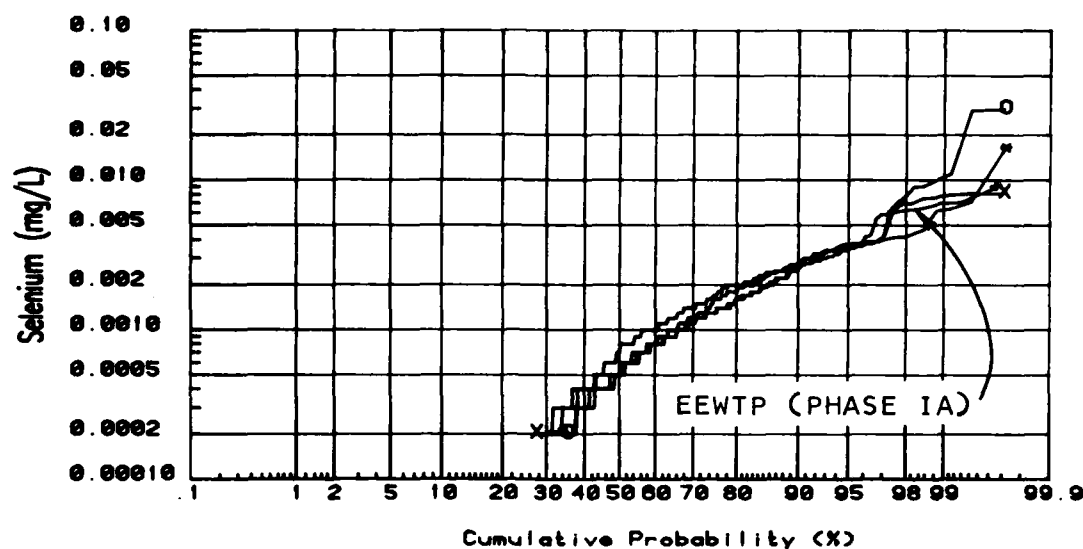
Selenium is toxic at high concentrations, although it is also a nutritional requirement. The FDA permits its addition to the feeds of poultry and swine. As is described below, selenium concentrations found in EEWTP finished water are not of health concern. All values are less than the NIPDWR MCL, and all are less than or equal to values observed in the local plants.

Figure 9.4-8(a) shows the probability plots of selenium measured in the EEWTP finished water during Phase IA and in local finished waters. As is shown in Table 9.4-3, the geometric mean for the EEWTP of 0.00051 is not significantly different from that of the local WTP with the highest geometric mean (0.00050 mg/L).

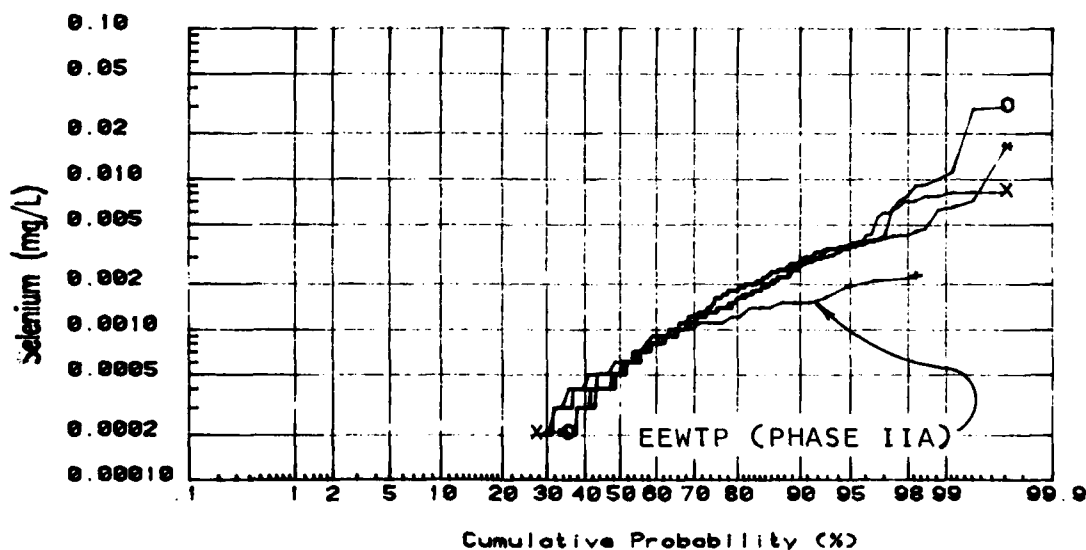
During the lime phase of operation, the probability plot for EEWTP finished water falls well below the plot for local finished waters; see Figure 9.4-9(b). Given the lack of chronic effect and the favorable comparison to local plants, it may be concluded that this trace element was not of health concern for EEWTP finished water.

### Silver

Data for silver concentrations in the EEWTP finished water during Phases IA and IIA and in local finished waters are shown in Figures 9.4-9(a) and (b). Almost all samples measured had concentrations below the detection limit of 0.0002 mg/L. Only a few values at each site had concentrations over the detection limit, with the EEWTP samples having concentrations generally lower or equal to those of the local plants. All samples measured in EEWTP finished water had concentrations far below the federal MCL of 0.05 mg/L. Therefore

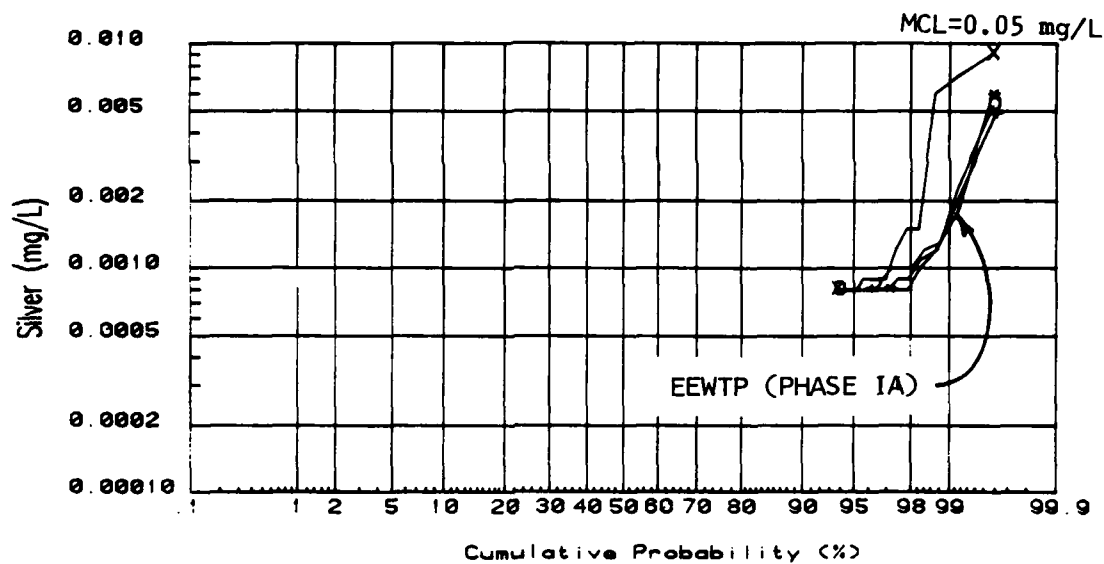


(a) Selenium in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)

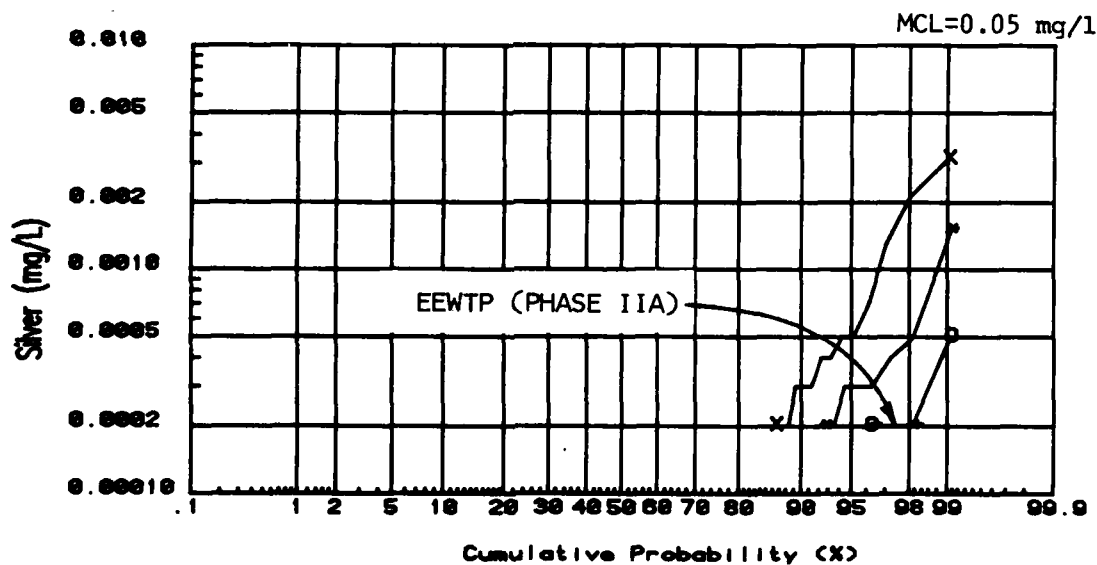


(b) Selenium in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

# SELENIUM IN EEWTP FINISHED WATER AND AT THREE LOCAL WTPs FIGURE 9. 4-8



(a) Silver in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Silver in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**SILVER IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9.4-9**

silver does not pose a concern for public health at the levels observed in EEWTP treated water.

#### TRACE METALS WITH FEDERAL SECONDARY DRINKING WATER REGULATIONS

Secondary MCLs were promulgated to protect public welfare; in the case of metals, these pertain to contaminants which may adversely affect the aesthetic quality of drinking water such as taste, odor, and color, rather than public health. They are not enforceable but represent guidelines for the States in the formulation of standards. Metals for which secondary standards exist include iron, manganese, copper, and zinc. Table 9.4-5 shows the number of samples for these metals and the percentage of samples in which their concentrations exceeded the secondary MCLs during the various phases of EEWTP operation.

##### Iron

The secondary MCL for iron is established at 0.3 mg/L, the level at which ferric oxide may begin to precipitate and create aesthetic problems. "Red water" problems leading to fixture staining, typically do not occur below 0.6 mg/L, and the taste threshold for iron is estimated at 1.0 mg/L. As is described below, 97 percent of the 278 samples taken during Phase IA and 100 percent of the 55 samples taken during Phase IIA were below the SMCL of 0.3 mg/L. The few higher values during the former phase indicate need for plant operational control; the lack of higher values during the latter phase indicate that such control is attainable.

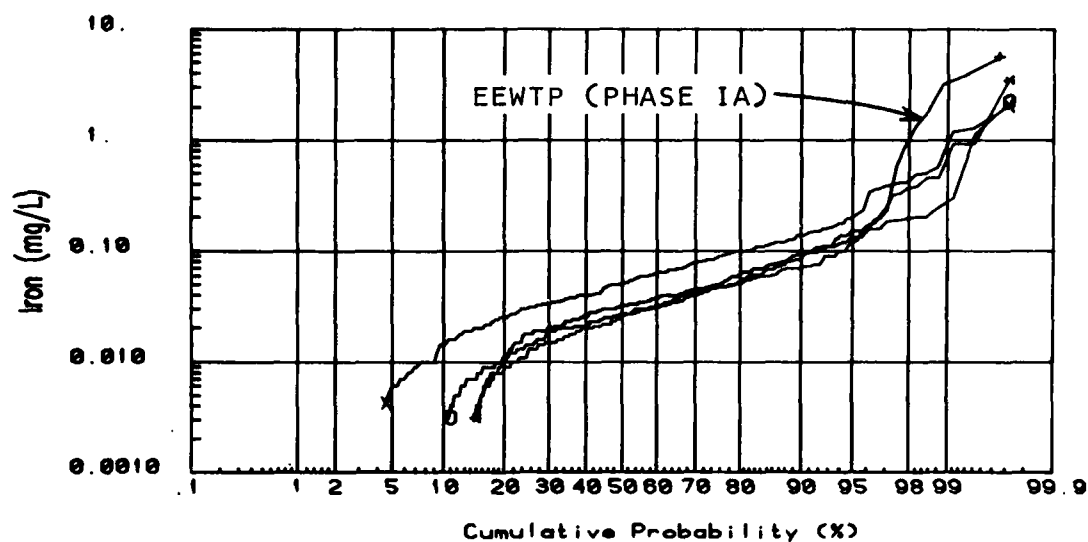
EEWTP finished water exceeded the federal secondary MCL of 0.3 mg/L in seven out of 278 samples, or 2.5 percent. The 95 percent confidence interval around this fraction is 1.0 percent to 5.1 percent. Phase IIA finished waters were never in excess of the SMCL.

Figures 9.4-10(a) and (b) show probability plots of iron concentration measured in Phases IA and IIA EEWTP finished water and in local plants during the entire study. During Phase IA, the sample concentrations at the EEWTP were below or equivalent to the concentrations for the local WTPs at most distribution percentiles, but the distribution diverges to significantly higher iron concentrations at the upper percentiles. This demonstrates that peak values for iron concentration in finished water at the EEWTP can increase far above the average. It is suspected that such peak values were due to release of previously accumulated iron oxides on pipe and clearwell surfaces, such as might occur with significant variations in product water pH. During Phase IIA, values obtained at the EEWTP remained well below those of the local plants.

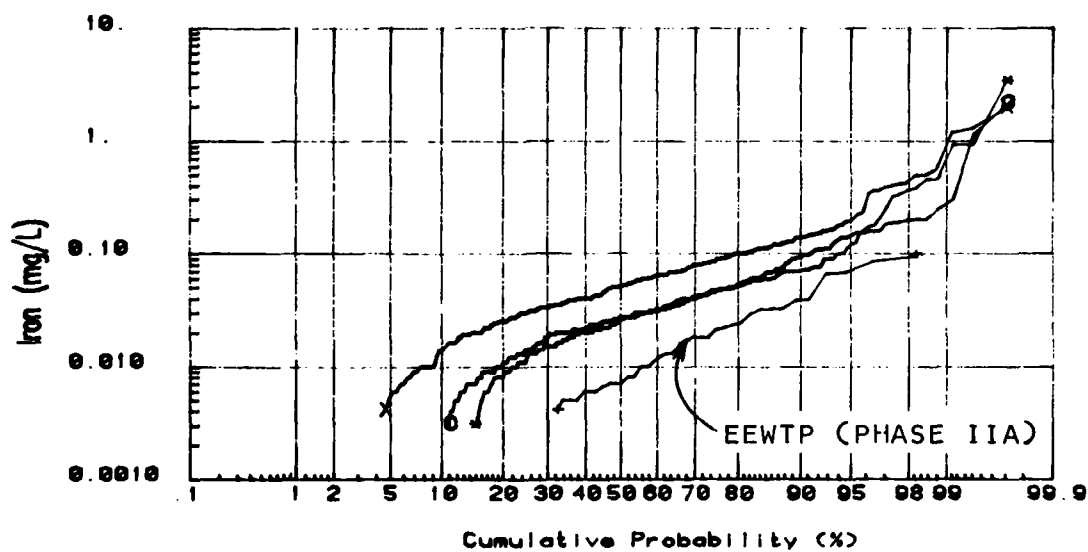
TABLE 9.4-5  
TRACE METALS IN EEWTP FINISHED WATERS COMPARED TO  
SECONDARY MCLS

Parameter	No. > MCL/ No. of Samples	Percent Exceeding	Upper 95% Conf. of % Exceeding	Lower 95% Conf. of % Exceeding
Copper: SMCL = 1.0 mg/L				
Alum-IA	0/26	0.0	—	—
Alum-IB	0/32	0.0	—	—
Lime-IIA	0/55	0.0	—	—
Iron: SMCL = 0.3 mg/L				
Alum-IA	7/278	2.52	5.07	1.02
Alum-IB	1/32	3.12	16.26	0.791
Lime-IIA	0/55	0.0	—	—
Manganese: SMCL = 0.05 mg/L				
Alum-IA	94/278	33.8	37.7	29.8
Alum-IB	1/32	3.12	16.3	0.0791
Lime-IIA	0/55	0.0	—	—
Zinc: MCL = 5 mg/L				
Alum-IA	0/26	0.0	—	—
Alum-IB	0/0	—	—	—
Lime-IIA	0/55	0.0	—	—

Trace Metals



(a) Iron in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Iron in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**IRON IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-10**

The highest values obtained in EEWTP finished water could cause intermittent red water in distribution systems and lead to staining and consumer complaints. This could represent a source of concern for aesthetics if this water were sent to distribution and should be addressed in plant operations. Such operational control is discussed in Chapter 7 of this report and is also closely related to manganese removal, as discussed below.

### Manganese

The secondary MCL of 0.05 mg/L manganese was established to avoid problems of black or brown tinted tap water associated with manganese oxides present in the water mains.

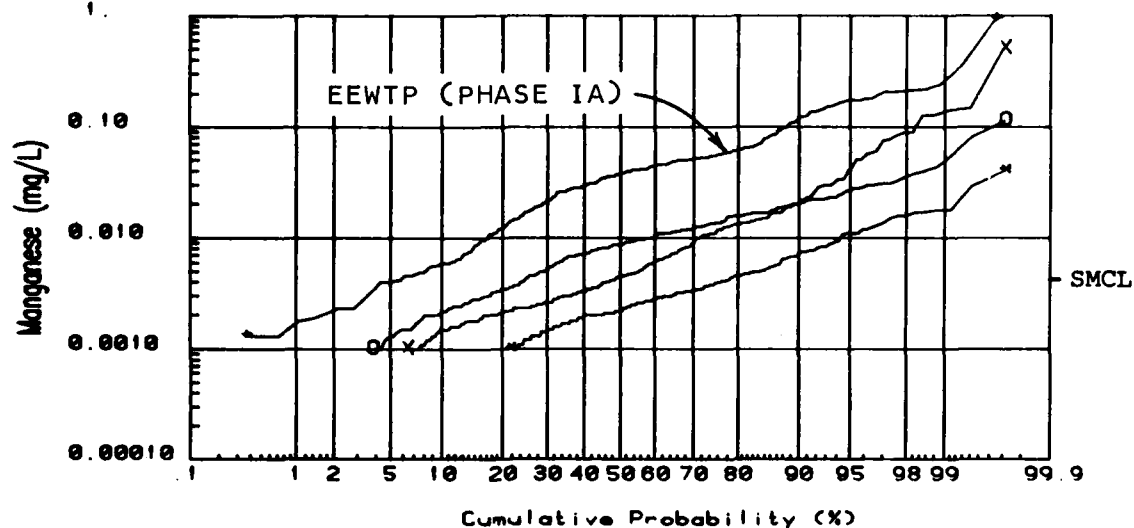
Alum Phase. During Phase IA, manganese in the finished water exceeded this SMCL in 94 out of 278, or in 34 percent of the samples, with upper and lower 95 percent confidence bounds of 30 and 38 percent, respectively. During Phase IB, the SMCL was exceeded only once out of 32 samples taken. During Phase IIA, the SMCL was never exceeded.

Figure 9.4-11(a) shows that the values obtained during Phase IA from the EETWP finished water were all higher than the local plants. This is a matter of some concern with respect to aesthetics and consumer acceptance. With oxidant addition and pH control in subsequent phases, however, this situation improved. Specifically, permanganate addition or intermediate ozonation in combination with elevated process water pH appeared to resolve the problem, as discussed in Chapter 10.

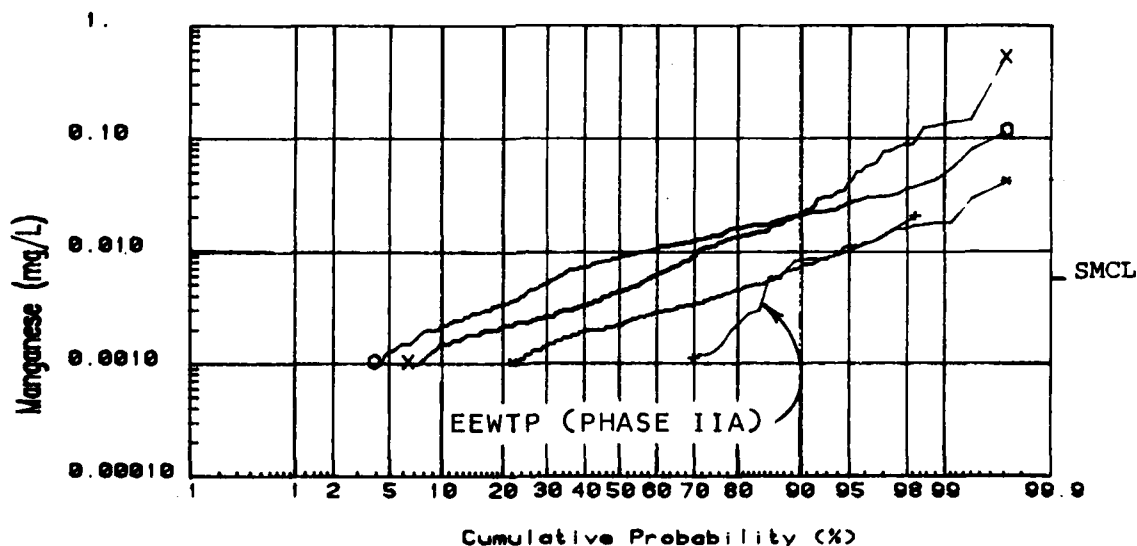
A closer look at the data is shown in Figure 9.4-12(a). Probability plots for the EEWTP finished water during the period between 1 December 1981 and 16 March 1982, when pH control measures were in effect, are displayed. In the latter part of Phase IA the manganese concentrations were still above the secondary standard in a large fraction of the samples. However, the large majority of these excursions all occurred during the period after potassium permanganate was terminated for testing purposes; other excursions are associated with short periods of low finished water pH. See Chapters 7 and 10 for further discussion. During Phase IB, with ozone as an oxidant and with consistent pH control, only one sample out of 32 was in excess of the standard, and the probability plot for the EEWTP finished water is almost indistinguishable from that of WTP3; see Figure 9.4-12(b). The geometric mean during Phase IB was less than that at WTP2, demonstrated at the 0.05 significance level.

Lime Phase. Phase IIA results are well below two of the local WTPs (Figure 9.4-11(b)), and the EEWTP geometric mean was significantly less than at the highest local plant. This was accomplished through operation at a higher pH throughout the sedimentation process, without the use of any oxidant prior to filtration. This suggests that changes in process operation were capable of controlling manganese concentrations in finished water. The problem of manganese removal is discussed in greater detail in Chapters 7 and 10 of this report.



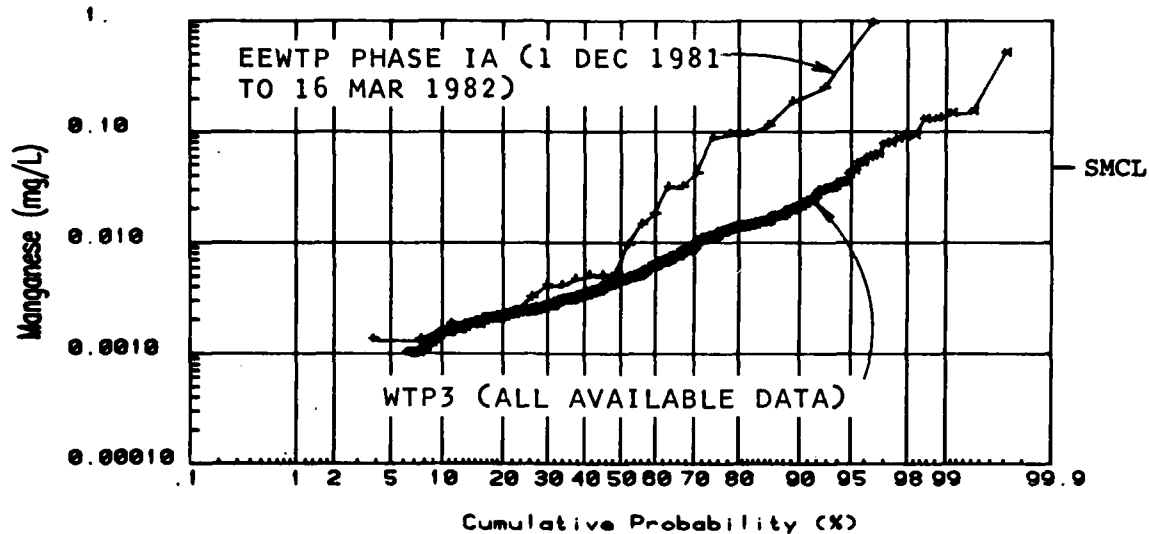


(a) Manganese in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)

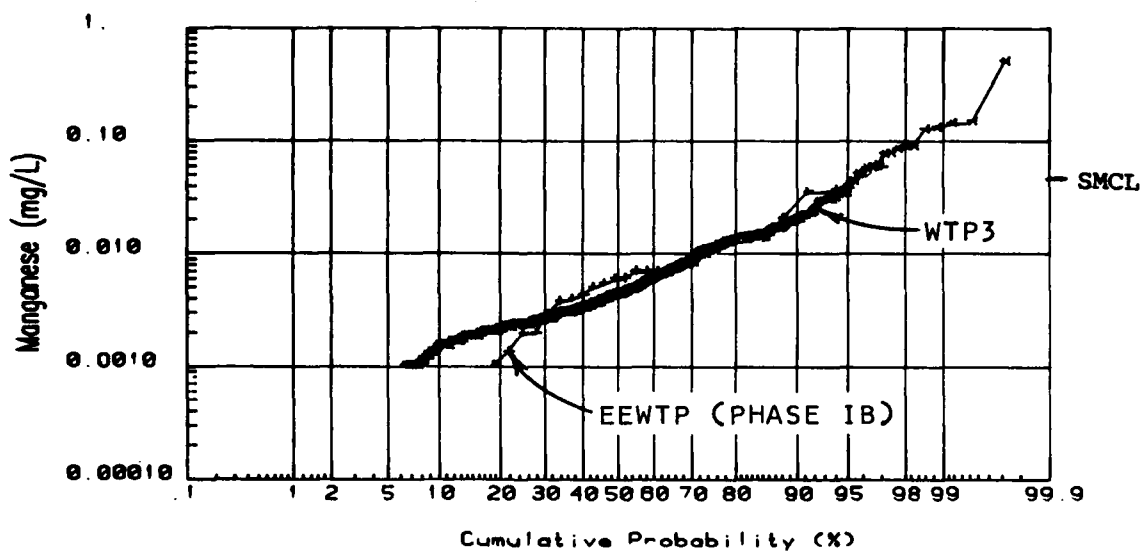


(b) Manganese in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**MANGANESE IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-11**



(a) Manganese in EEWTP finished water (1 December 1981 to 16 March 1982 - Phase IA after pH control) and WTP3 (all available data)



(b) Manganese in EEWTP finished water (16 March 1982 to 6 July 1982 - Phase IB) and WTP3 (all available data)

**MANGANESE IN EEWTP FINISHED WATER  
COMPARED TO RESULTS FROM WTP3  
(PHASES IA AND IB)  
FIGURE 9. 4-12**

## Trace Metals

### Copper

The sample probability distributions for copper in EEWTP finished water and in local finished waters are shown in Figure 9.4-13(a) and (b). All measured data fall below the SMCL of 1 mg/L. The geometric mean of copper concentration measured in EEWTP finished water was below that of one local treatment plant, but the difference is significant only for the lime phase (Table 9.4-3). As can be seen in the plots, the values at the EEWTP fall below those at local plants except for upper percentiles in Phase IA. Since the values are far below the secondary standard, it is quite unlikely that copper in this water would contribute significantly to taste problems in a distribution system. Similarly, these levels are far below the levels of several mg/L which are associated with acute copper toxicity.

### Zinc

Zinc is an essential nutrient for the human diet. The research literature on its effects suggest that zinc intake can protect against lead toxicity. No toxic effects of zinc are likely except at concentrations far above the SMCL of 5 mg/L. In fact, as far as the general population is concerned, major concern with zinc occurs over zinc deficiency rather than excess.

Data for zinc concentrations in EEWTP finished water and in local plants are shown in Figures 9.4-14 (a) and (b). The geometric mean concentration at the EEWTP during all phases was significantly above that at all other plants, in some cases by more than an order of magnitude. However, all data measured fall far below the secondary MCL for zinc of 5 mg/L. Since all EEWTP data fall well below this level, it is unlikely that any health or taste effect would be associated with zinc in EEWTP finished water.

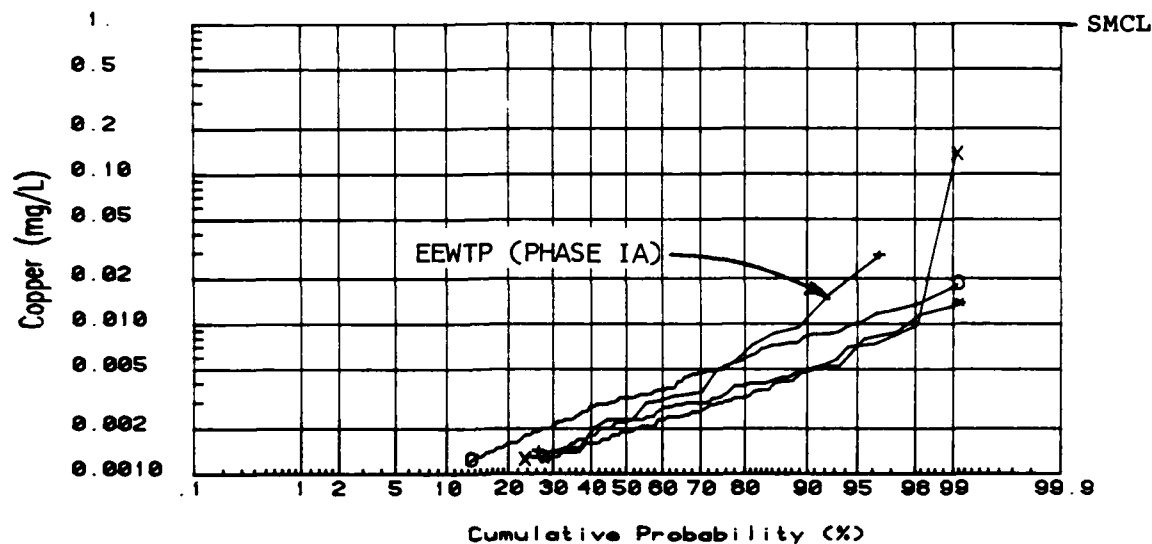
### OTHER TRACE METALS OF POTENTIAL HEALTH CONCERN

Not all of the trace metals for which there are potential health concerns have been regulated by the federal government. For those parameters without MCLs, evaluation of the EEWTP finished waters must be based solely on a comparison to current drinking waters in the MWA. For these parameters, examination of the EEWTP data suggest that during Phase IA the EEWTP finished water is equal or worse than all local finished waters for the following metals: antimony, nickel, and thallium. Therefore, these metals are discussed below. For comparison, results from Phase IIA are also shown, although the lime phase compared favorably with MWA finished water for all of these elements.

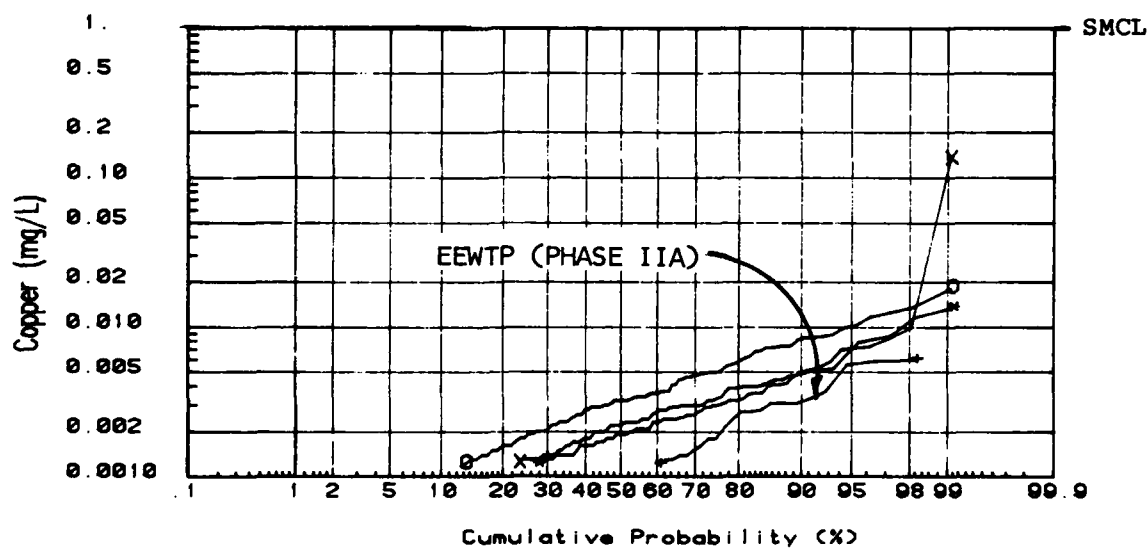
For other non-regulated trace elements, either no health effects are known or the EEWTP concentrations were clearly below those of the other plants.

### Antimony

Antimony is associated with acute toxicity when ingested at dosages of 100 mg or more. There is no evidence for chronic toxicity of antimony when present in

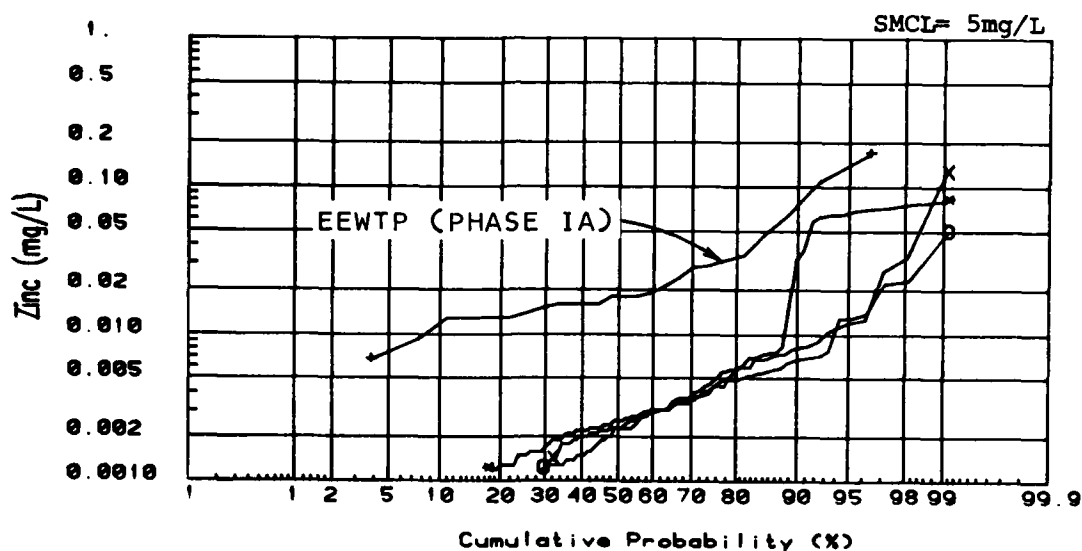


(a) Copper in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTP's (All Available Data)

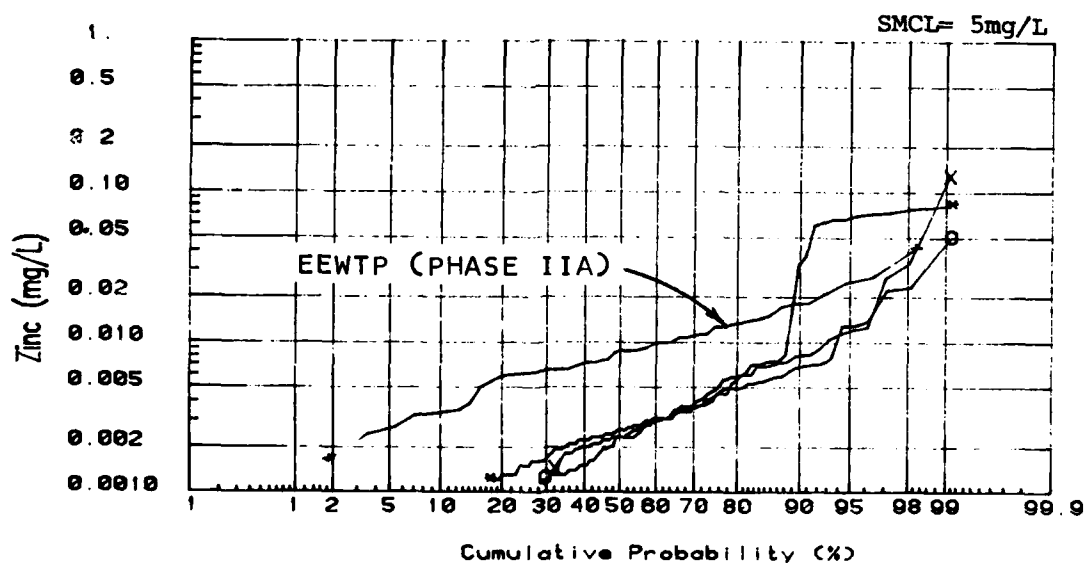


(b) Copper in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTP's (All Available Data)

**COPPER IN EEWTP FINISHED WATER AND AT THREE LOCAL WTPs**  
**FIGURE 9. 4-13**



(a) Zinc in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA) and at three local WTPs (all available data)



(b) Zinc in EEWTP finished water (16 July 1982 to 1 February 1983 - Phase IIA) and at three local WTPs (all available data)

**ZINC IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-14**

## Trace Metals

low concentrations. The EPA has set a water quality criterion for protection of human health from toxic properties of antimony ingested through water at 0.146 mg/L (EPA, 1980d).

The estimated geometric mean concentration in the EEWTP Phase IA finished water is significantly higher than in all of the local plants, and the EEWTP levels are generally higher at each percentile. Nevertheless, the EPA water quality criterion of 0.146 mg/L was not exceeded in any samples from EEWTP finished water during Phase IA. Therefore antimony in finished water is highly unlikely to have any public health impact.

Because observed antimony levels at all sites were judged to be insignificant with respect to health impact, this element was dropped from the sampling program on 16 March 1982. Thus, Phase IB and Phase IIA data for antimony were not obtained. The data from the latter portion of Phase IA do indicate that antimony levels were lowered when plant pH was maintained sufficiently high. Because finished water pH during Phases IB and IIA was consistently higher than during Phase IA, antimony is also not a parameter of concern for these other phases of operation.

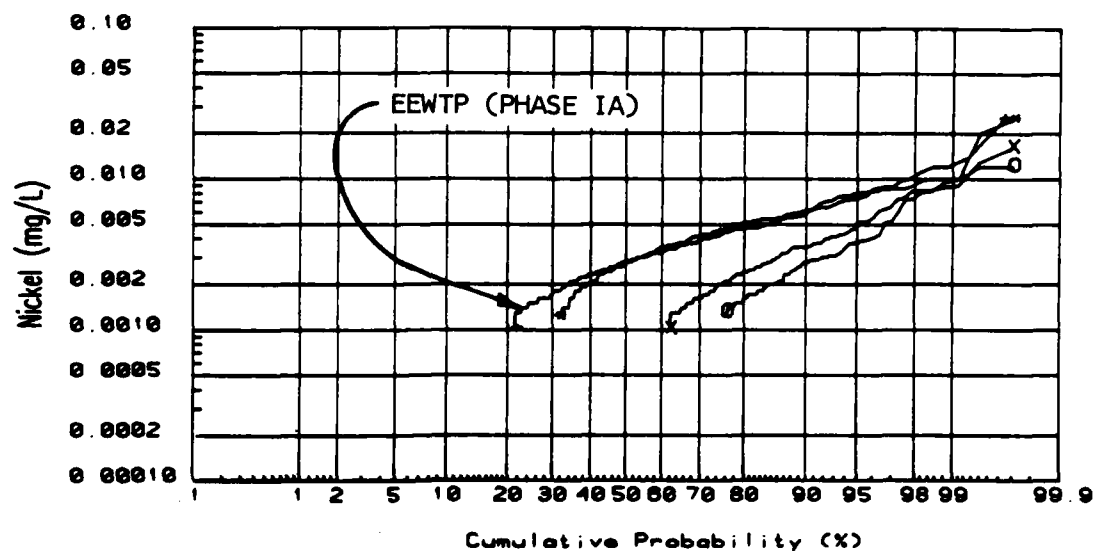
### Nickel

Human exposure to nickel results from naturally occurring levels of this trace metal in food and food-processing equipment or fungicides. Inorganic nickel has relatively low toxicity when ingested. For the protection of human health from toxicity of nickel, the EPA has recommended a water quality criterion of 0.0134 mg/L for ingestion through water and contaminated aquatic organisms, based on a no-effect level in animal studies (EPA, 1980d). That is, the criterion is estimated to correspond to doses which have no toxic effect on the population.

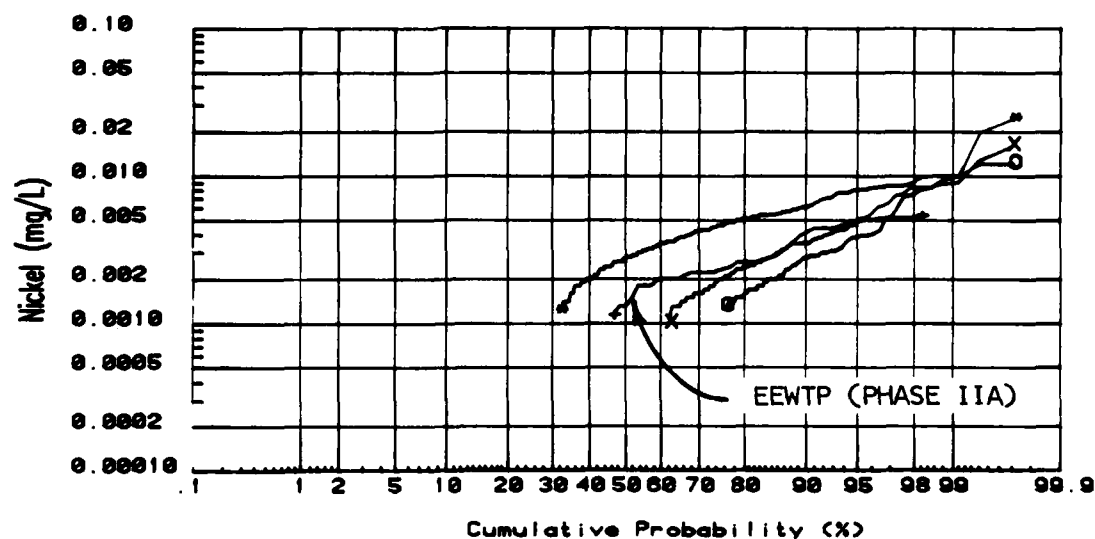
Concentration data for nickel in the EEWTP finished water during Phase IA and in local WTPs over the entire sampling period are shown in Figure 9.4-15(a). The plots show that nickel levels in the EEWTP were roughly equivalent to those in WTP1 during Phase IA. A hypothesis test on the geometric mean, however, show that the EEWTP value during Phase IA was greater than the WTP1 geometric mean at the 0.05 percent significance level.

During Phase IB the estimated geometric mean of the nickel data decreased but the slope of the distribution (the spread factor) increased. In both cases the levels of nickel concentration are roughly equivalent to those in WTP1 but were clearly above WTP1 values for parts of the sample probability distribution. During Phase IIA, however, nickel values dropped slightly, such that the Phase IIA geometric mean was significantly less than the WTP1 value. As Figure 9.4-15(b) illustrates, values at all percentiles during Phase IIA were below those at WTP1.

The estimated arithmetic mean concentration of nickel in EEWTP finished water during Phases IA and IIA were 0.0032 mg/L and 0.00166 mg/L, respectively. These values represent the level of chronic exposure to nickel



(a) Nickel in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Nickel in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**NICKEL IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 4-15**

## Trace Metals

experienced by populations (as opposed to acute exposure). Considering the low toxicity of this element and the fact that levels in the EEWTP do not differ markedly from those in local plants, nickel does not pose a public health problem for EEWTP finished water during any phase of operation.

### Thallium

There were very few thallium samples at any site which had concentrations above the detection limit of 0.0009 mg/L. Of the positive samples, the EEWTP, Phase I finished water had more and higher positive values than in the local plants. Six samples had detectable concentrations of thallium in the EEWTP Phase I finished water with the maximum concentration less than 0.003 mg/L.

Thallium compounds are toxic to humans. The lethal dose of thallium salts for an adult is about 5 to 50 mg/kg of body weight. For an adult to obtain this dose from drinking two liters of water, a concentration of 100 to 1000 mg/L of thallium acetate as thallium would be required. The EPA has recommended a water quality criterion of 0.013 mg/L to correspond to a no-effect level. Since the concentration of thallium in the EEWTP finished water during Phase IA was not detected in about 98 percent of the samples, and was below the no-effect criterion in all of the samples, it is unlikely that thallium at levels found in EEWTP finished water would have any consequences for public health.

Because of the small number of positive findings and the generally low observed levels, thallium was dropped from the sampling program on 16 March 1982. Thus, Phase IB and Phase IIA data are unavailable for this parameter. Based on the lower observed values for all other trace metals, it is highly unlikely that thallium reached levels of concern during these latter phases.

## SUMMARY

### ALUM PHASE

Among all the trace metals measured in EEWTP finished water, data for several metals of health significance were examined in detail. The only metal for which concentrations ever exceeded a Federal Primary Standard was mercury, (three out of 279 samples during Phase IA). However, hypothesis testing reveals that the estimated geometric mean of mercury concentration was not significantly above that at a local plant, at the 0.05 significance level. Chronic exposure to mercury would be approximated by the arithmetic mean. This was estimated, during Phase IA, to be 0.00032 mg/L an order of magnitude less than the MCL. Since the highest levels of mercury observed are far below those associated with acute toxic effects, no significant health effects would be expected with mercury in EEWTP finished water during Phase IA.

Metals with Federal Secondary Standards include iron and manganese, for which the EEWTP finished water during Phase IA exceeded the standards in 2.5 and 34 percent of the samples, respectively. These metals are associated with aesthetic problems such as colored water in distribution systems when present



## Trace Metals

at high concentrations. They are not responsible for public health concerns. Examination of the data demonstrates that the application of lime for pH control and other changes in process operations had a very significant effect on iron and manganese removals. During Phase IB, with intermediate ozonation and pH control, the percentage of samples with manganese levels exceeding the secondary standard was reduced to three percent. The effect of process performance on iron and manganese removals is discussed in Chapters 7 and 10 of this report.

For other metals of interest which lack federal standards, the EEWTP finished water during Phase IA was compared to the local MWA plants. For some of these metals the estimated geometric mean of EEWTP samples was higher than those for local plants. Even with chronic exposure to the EEWTP finished water, however, comparison to water quality criteria showed that there would be no cause for public health concern.

### LIME PHASE

Levels for all trace metals in Phase IIA were less than those observed during the alum phases, and only for zinc did the lime phase finished water have an estimated geometric mean which was significantly above those observed in finished waters from local MWA plants. Because zinc levels were well below the federal SMCL, and because there are no known or suspected adverse health effects of low level zinc, this parameter is not of concern.

Other parameters which were at times problematic during the alum phases, such as iron and manganese, were maintained at acceptable levels with lime treatment, well below observed levels in the current MWA supply.

## SECTION 5

### RADIOLOGICAL PARAMETERS

#### INTRODUCTION

Radioactivity in drinking water may come from a wide range of sources, including natural radioactive elements and their decay products, contamination from atmospheric testing of nuclear weapons, local discharge of radiopharmaceuticals and the possible entry of radioactivity into watersheds from the use and processing of nuclear fuel. Of the natural radionuclides, some were incorporated in the earth at its formation, whereas others, such as tritium and carbon-14, are produced continuously by cosmic ray bombardment of the earth's atmosphere.

Radioactive decay is a spontaneous process in which a radionuclide transforms to a resulting nuclide of lighter mass, releasing radiation (energy and/or particles) in the process. There are several forms of radiation which may be emitted, and several radiations may be emitted in a single decay. The three most common forms of radioactive disintegration are alpha, beta, and gamma decay. Alpha decay is prevalent among the heavy elements and involves the reduction of mass of a nuclide through emission of an alpha particle, the nucleus of a helium atom. In beta decay, a radioactive nuclide with an excess of neutrons becomes more stable by converting a neutron into a proton in the nucleus with the emission of a beta particle (a negatively charged high-speed electron). Gamma decay is the de-excitation of a nucleus which is stable with respect to alpha or beta decay, but with an excess of internal energy. The excess energy is released either through the emission of gamma rays (photons of electromagnetic radiation) or through the emission of a "conversion" electron.<sup>1</sup> The excited nuclides which emit gamma radiation result from either prior alpha or beta radiation or the absorption of energy from another radiation. Thus, gamma rays will usually be emitted simultaneously with alpha or beta particles.

Alpha emitters include many natural radionuclides, such as those produced by the decay of uranium-238 and thorium-232; these are widely distributed throughout the earth's crust. Of the natural alpha-emitters that occur in drinking water, most appear to be bone seekers. That is, the element tends to be retained primarily in bone tissue, where much of it will remain deposited.

<sup>1</sup> The emission of an electron with a kinetic energy equal to the nuclear transition energy less the orbital binding energy is a process known as "internal conversion".

## Radiological Parameters

Of these bone seeking radionuclides, radium-226 and its daughters and the daughters of radium-228 are the isotopes most generally recognized as being of concern in drinking waters (NAS, 1977). Radium is found frequently in ground waters, particularly in the Midwest of the United States; concentrations in surface supplies are generally low.

Of the beta-emitters, those which have received the most attention in drinking water include strontium-90, cesium-137, iodine-131, tritium, and carbon-14. These have been cited both because they account for a major part of the potential dose from nuclear fission and activation products, and because of their biological significance. Radium-228 is another beta-emitter of potential concern, primarily because it decays very slowly to a series of daughter products which can produce alpha-particle doses to human tissue.

Although no level of radioactivity can be considered as harmless, the EPA has recognized that, for sufficiently low concentrations of radionuclides in drinking water, the risk to an individual is small (EPA, 1975b). The potential health effects associated with radionuclides in drinking water may be minor relative to radiation from other sources, including unavoidable background radiation from cosmic rays and from the decay of radioactive elements in the earth's crust and atmosphere. Therefore, in promulgating Maximum Contaminant Levels for radiological parameters, the EPA used previously published exposure and risk data and conservatively assumed that the radiation effects are linearly proportional to dose. According to the EPA, the degree of conservatism is likely to be less for ingested alpha-emitting radionuclides than for those man-made sources of radioactivity which decay by beta and gamma ray emission (EPA, 1975b).

The basis for evaluating the water quality of EEWTP finished drinking water with respect to radiological parameters has been to examine those radiological parameters which are regulated by the National Interim Primary Drinking Water Regulations. For those species, comparison to the standard gives an indication of the acceptability of the treated water. In addition, for the gross measures of alpha and beta radiation, it is informative to compare the concentrations observed in EEWTP finished water to those in local finished waters in the Metropolitan Washington Area.

### OVERVIEW

Statistical information for the radiological parameters monitored during this project is summarized in Table 9.5-1, for EEWTP finished water during the three primary phases of operation and for local finished waters during the two years of monitoring. Geometric means, arithmetic means, medians and 90 percentile values are included, where available.

Table 9.5-2 shows the results of hypothesis tests comparing geometric mean concentrations of gross alpha and gross beta radiological emissions in EEWTP finished waters to the mean concentration in the local finished water with highest levels of each parameter. This comparison shows whether the EEWTP

### Radiological Parameters

**TABLE 9.5-1**

[illegible]

# Radiological Parameters

TABLE 9.5-2  
APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES IN GEOMETRIC MEANS  
FOR RADIOLOGICAL PARAMETERS IN FINISHED WATERS

Parameter	Highest Geom Mean at Local WTP	Phase of EEWTP Operation	Geom Mean At EEWTP	Number of Degrees of Freedom	T	t-Statistic for 0.05 Signif. Level	Significant Difference
Gross Alpha	0.120	Alum-IA Alum-IB Lime-IIA 1	0.100 0.030 —	54.5 6.4 —	-0.63 -1.46 —	1.67 1.92 —	No Signif. Diff. No Signif. Diff. —
Gross Beta	1.98	Alum-IA Alum-IB Lime-IIA	5.93 5.02 5.27	65.1 62.9 44.6	5.54 4.97 4.51	1.67 1.67 1.68	WTP2 < EEWTP WTP2 < EEWTP WTP2 < EEWTP

1. Insufficient quantified data for estimation of geometric mean in EEWTP finished water.

## Radiological Parameters

finished water had higher geometric mean values than the highest local plant, with a statistical significance at the 0.05 level test.

Results for each parameter are discussed in further detail below.

### COMPARISON TO PRIMARY STANDARDS

The NIPDWR MCLs for radiological parameters are shown in Table 9.5-3, together with a simplified description of the associated monitoring requirements. The provisions of the NIPDWR monitoring requirements were used to set-up guidelines for monitoring finished waters during this project. Specifically, gross alpha and gross beta levels were carefully monitored to check that:

1. Gross alpha counts plus two standard deviations did not exceed 5 pCi/L (thus ensuring, with good confidence, that radium-226 levels could not exceed 5 pCi/L).
2. Gross beta counts plus two standard deviations did not exceed 8 pCi/L, (thus ensuring that Strontium-90 levels could not exceed 8 pCi/L).

In any case where the gross alpha criterion was exceeded, protocols called for radium analysis. Similarly, if the gross beta criterion was exceeded, analysis was conducted for Strontium-90. In the case of EEWTP samples, values at the blended influent were also examined relative to these criteria, in an effort to be conservative.

In no case did any monitored finished water sample exceed the federal MCL for gross alpha or gross beta. In fact, gross alpha levels during the project did not ever exceed the criterion for radium analysis and this test was never conducted. The gross beta criterion was exceeded on a number of occasions, but in no case did the subsequent analysis for Strontium-90 indicate levels in excess of the MCL of 8 pCi/L. In fact, the highest level found in EEWTP finished water was 2.2 pCi/L during Phase IA, over three and one half times less than the MCL.

Tritium levels in all finished water samples were below the analytical detection limit of 1000 pCi/L, and were thus over twenty times less than the federally regulated MCL.

### COMPARISON TO LOCAL FINISHED WATERS

As indicated in Table 9.5-1, the EEWTP finished water sometimes showed levels of radiological contamination which were higher than observed at the local WTPs. Because of the potential health concerns associated with these parameters, this issue is discussed in further detail below. Table 9.5-3 shows the statistical comparison of geometric means between the EEWTP finished water and the local finished waters for both gross alpha and gross beta. These are discussed in further detail below.

# Radiological Parameters

TABLE 9-5-3  
SUMMARY OF NATIONAL INTERIM PRIMARY DRINKING WATER REGULATION MCLs FOR RADIONUCLIDES

Parameter	MCL	Monitoring Basis for Compliance
Gross Alpha	15 pCi/L (including radium-226 but excluding radon and uranium)	Average or composite of quarterly sampling.
Radium	50 pCi/L (combined radium-226 and radium-228)	Gross alpha analysis may be substituted, provided that gross alpha activity does not exceed 5 pCi/L at a confidence level of 95 percent (average activity plus 1.65 times the standard deviation). When the gross alpha activity exceeds 5 pCi/L, analysis for radium-226 is required in the same or equivalent sample; if the concentration of radium-226 exceeds 3 pCi/L, analysis for radium-228 is required.
Beta Particle and photon radioactivity from man-made radionuclides	Concentration of radionuclides shall not produce an annual dose equivalent greater than 4 millirem/yr. Average annual conc. assumed to produce a total body or organ dose of 4 mrem/yr.	Average or composite of quarterly sampling; Compliance may be assumed without further analysis if the average annual concentration of gross beta activity is less than 5 pCi/L and the average annual concentrations of tritium and strontium-90 are less than 8 pCi/L and 20,000 pCi/L, respectively, provided, that if both parameters are present the sum of their annual dose equivalents to bone marrow shall not exceed 4 millirem/yr.
Tritium	20,000 pCi/L	
Strontium-90	8 pCi/L	
Other man-made radionuclides	Calculated on the basis of a 2 liter per day drinking water intake using the 168 hour data listed in "Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure", (U.S. Department of Commerce, 1963)	

## Radiological Parameters

### GROSS ALPHA

#### Alum Phase

The geometric mean of gross alpha activity observed in Phase IA EEWTP finished water was less than that observed at WTP3, but not significantly so. The sample distributions in the Phase IA product water and three local MWA waters are shown in Figure 9.5-1(a). This plot illustrates that the highest levels of gross alpha observed in the Phase IA finished water were greater than the highest levels observed in local plants.

Since EPA MCLs for radiological parameters are based on the assumption that the radiation effects are linearly proportional to dose, it is useful to examine the arithmetic average dose at each site, as shown in Table 9.5-1. The average levels of gross alpha in the Phase IA and IB finished waters were 0.28 and 0.24 pCi/L, respectively. These levels are slightly below the average gross alpha level of 0.29 pCi/L at WTP3. The radiation effects from drinking the EEWTP Phase IA product water could thus be considered, using the linear assumptions adopted by the EPA, to be roughly comparable to all of the current MWA supplies.

More importantly, however, the levels of radiation observed in these drinking waters compare quite favorably to the federal MCL of 15 pCi/L (over fifty times less), and can be considered as negligible relative to radiation from other sources. It is important to note that even if the radiation level in a drinking water were at the EPA MCL, this would be equivalent, using assumptions of two liters per day of water consumption, to an annual dose of only 4 millirem. This is over forty times smaller than the annual dose of 170 millirem per year which was established by the Federal Radiation Council (FRC) as a protection guide for all sources of total body exposure except radiation received for medical purposes.

#### Lime Phase

Gross alpha emissions were not detected in any samples of the EEWTP finished water during Phase IIA. With consideration of the analytical detection limit for gross alpha (0.1 pCi/L), it is clear that this parameter is not of concern in the lime phase finished water.

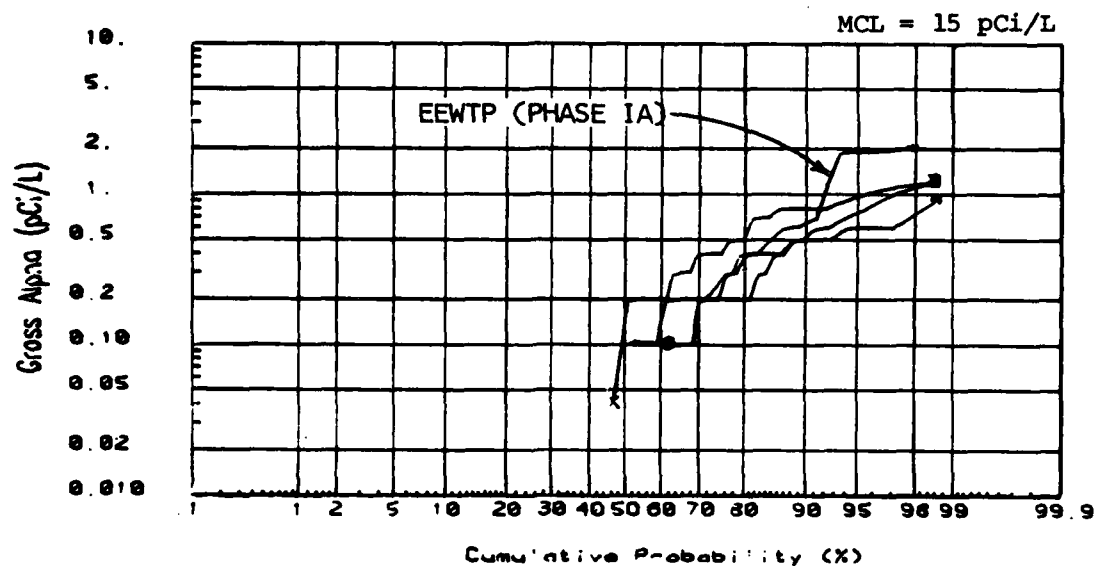
### GROSS BETA AND STRONTIUM-90

#### Alum Phase

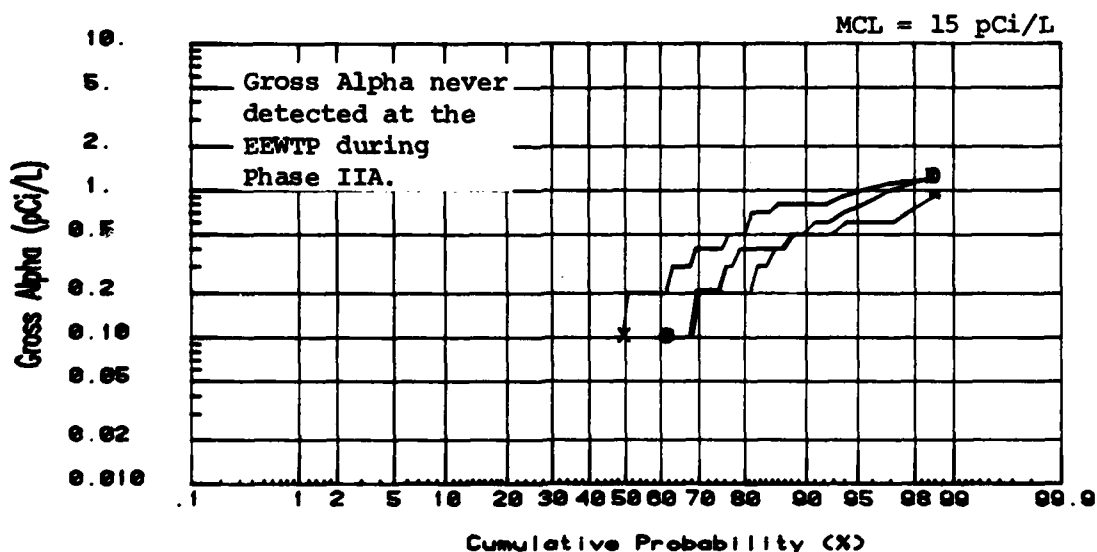
As indicated in Table 9.5-1, the geometric mean level of both gross beta emissions and strontium-90 concentrations during Phase IA were significantly greater than in the local finished waters. This is illustrated in Figure 9.5-2(a), which shows distribution plots of gross beta results at all four sites.

Gross beta radiation is generally indicative of man-made radionuclides. It is likely that the source of the higher levels in EEWTP finished water is the use



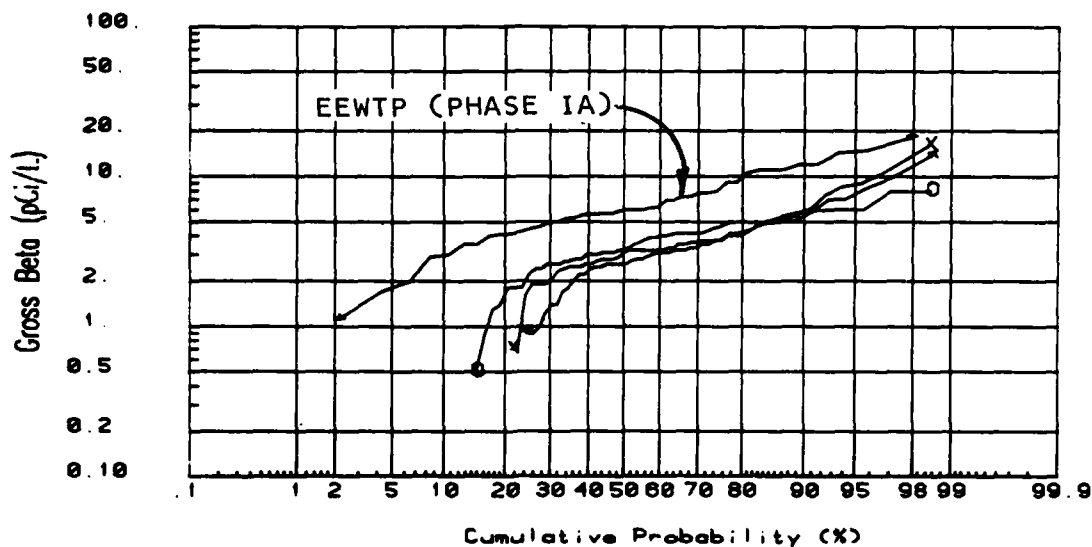


(a) Gross Alpha in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)

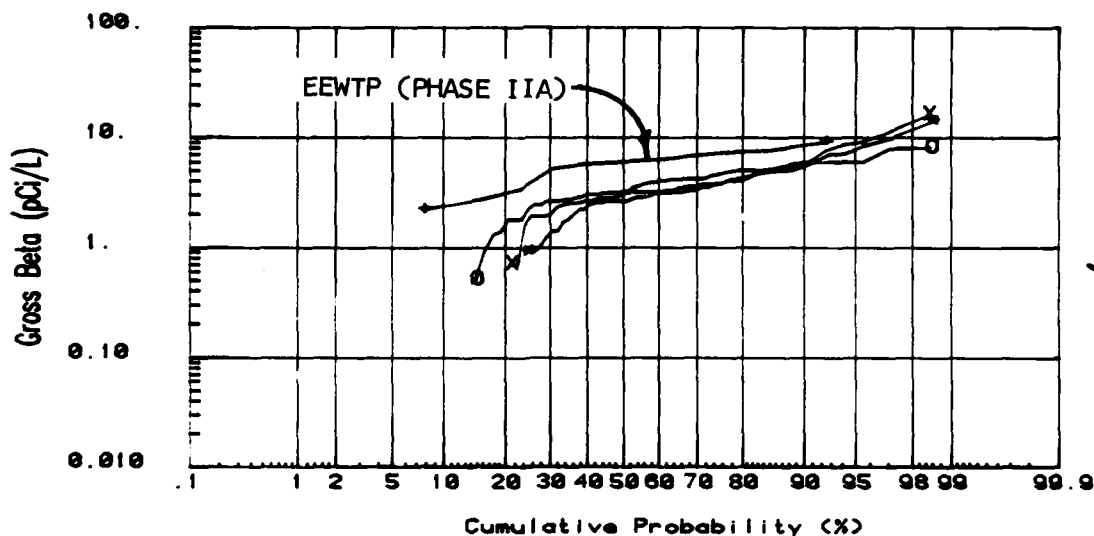


(b) Gross Alpha in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**GROSS ALPHA IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 5-1**

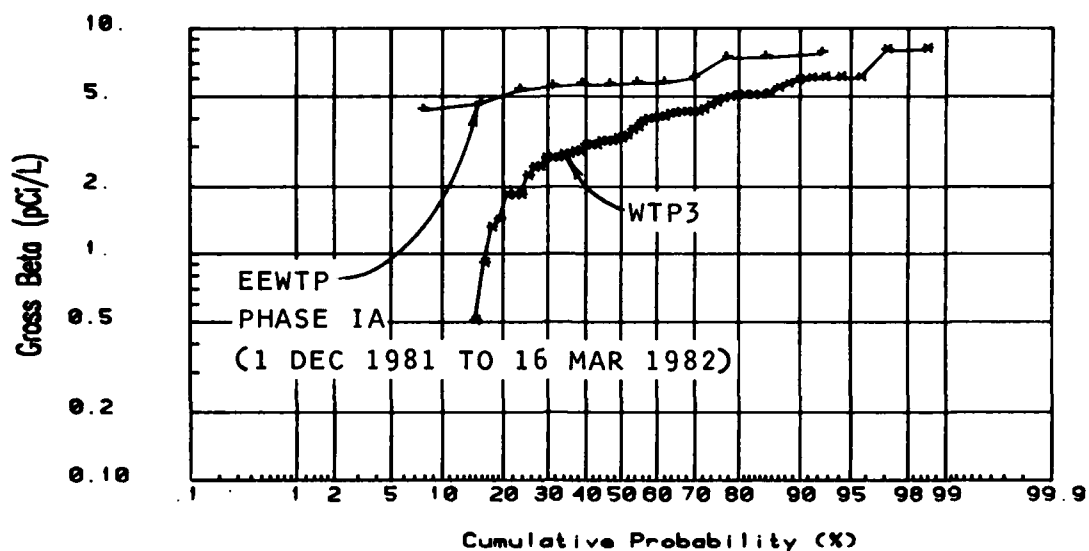


(a) Gross Beta in EEWTP Finished Water (16) March 1981 to 16 March 1982 Phase IA) and at Three Local WTPs (All available Data)

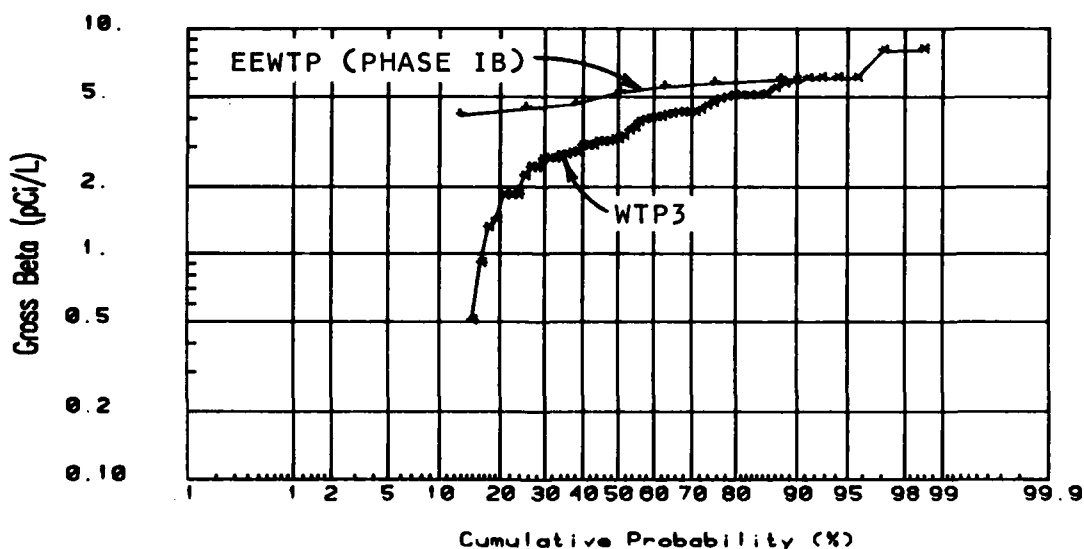


(b) Gross Beta in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**GROSS BETA IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 5-2**



(a) Gross Beta in EEWTP finished water (1 December 1981 to 16 March 1982 - Phase IA after pH control) and WTP3 (all available data)



(b) Gross Beta in EEWTP finished water (16 March 1982 to 6 July 1982 - Phase IB) and WTP3 (all available data)

**GROSS BETA IN EEWTP FINISHED WATER  
COMPARED TO WTP3  
(PHASES IA AND IB)  
FIGURE 9. 5-3**

## Radiological Parameters

increment loading in Blue Plains wastewater associated with commercial and industrial use of water (eg, radiopharmaceutical use in hospitals).

An examination of the arithmetic average concentrations at the finished water sites shows that gross beta activity in EEWTP finished water was, on the average, about twice the highest observed level at a local WTP, and health risks would be estimated to be approximately twice as high. However, as with levels of gross alpha, the levels of gross beta were well below the federal MCL. The average gross beta level of 2.14 pCi/L in Phase IA is more than twenty times less than the 50 pCi/L standard and may conservatively be considered to be of negligible health significance in relation to total exposure from all sources. Similarly the strontium-90 average concentration of 1.11 pCi/L is less than one seventh the MCL, which was based on the annual concentration assumed to produce a total human body dose of four millirem per year.

### Lime Phase

Gross beta and strontium-90 levels observed in the Phase IIA finished water were generally higher than observed in the local plants, as illustrated in Figure 9.5-2(b). The estimated geometric mean level for gross beta during Phase IIA, while above the estimated mean at the highest local plant, was not significantly different at the 0.05 significance level.

Although the higher observed levels do indicate an increased risk relative to the monitored MWA supplies, the implied radiation dose is quite low, being even less than that associated with the alum phase finished water. Similar arguments would therefore apply, and gross beta radiation should not be considered as an issue of concern with respect to potential health effects from EEWTP finished water.

## SUMMARY

Levels of radioactivity in the EEWTP finished water were observed to be higher than the local supplies during all phases of operation and particularly with respect to the man-made radionuclides, as measured by gross beta activity. The observed levels were, however, far below the federal standards for drinking water, and much less than many groundwater supplies currently used for drinking water. In fact, the levels of radioactivity observed in the EEWTP finished water are considered to be negligible relative to unavoidable background radiation from other sources. Regarding the suitability of EEWTP finished water as a drinking supply, concentrations of radiological parameters do not pose health related concern.

## SECTION 6

### MICROBIOLOGICAL PARAMETERS

#### INTRODUCTION

Pathogens which may be present in drinking water represent a wide variety of organisms. The principal microbiological contaminants in drinking water are bacteria, viruses and protozoan parasites. Table 9.6-1 summarizes the etiology of waterborne outbreaks reported between 1971 and 1978 (Craun, 1981). By far the largest category was attributed to acute gastrointestinal illness of unknown etiology. It is believed that many of these outbreaks were caused by viral pathogens which could not be identified in the laboratory. In order of the number of cases of illness, the identified agents are Giardia, a protozoan; Shigella, a bacterium; Hepatitis type A, a virus and Salmonella, a bacterium.

Salmonella, parasites (including Giardia) and enteric viruses were monitored during the project. However, Hepatitis A and Norwalk Agent viruses could not be detected using the assay methodology in this study. Isolation of other enteric viruses is at best an indicator of the presence of Hepatitis A and Norwalk Agent although no correlation has been shown to date. It has been suggested that several of the enteric viruses which can be isolated and identified with the project method are transmitted by drinking water but no rigorous epidemiological studies exist affirming this hypothesis.

TABLE 9.6-1  
CASES OF WATERBORNE DISEASE IN THE UNITED STATES  
1971-1978

<u>Illness</u>	<u>Number of Outbreaks</u>	<u>Percent</u>
Acute Gastroenteritis	123	55
Chemical Poisoning	22	10
Giardiasis	24	11
Shigellosis	20	9
Enterotoxigenic <u>E. coli</u>	2	0.9
Salmonellosis	7	3
Hepatitis A	15	6.7
Typhoid ( <u>Salmonella typhi</u> )	4	1.8
Viral Gastroenteritis	4	1.8
<u>Campylobacter</u> Gastroenteritis	2	0.9

## Microbiological Parameters

Additional organisms formerly thought not to cause waterborne illness and others which have been recently discovered have made the picture more complex, and may be partly responsible for a recent increase in reported outbreaks. (Craun and Gunn, 1979 and Craun, et al., 1976). Examples are (1) Yersinia enterocolitica, a bacterium formerly thought to be only a foodborne pathogen, which was suspected to be the causative agent in a waterborne outbreak involving 750 cases of acute gastrointestinal illness at a Montana ski resort (Eden, 1977); (2) Legionella pneumoniphila, the etiological agent of Legionnaire's Disease, which appears to be a waterborne disease with route of entry being aerosols from contaminated water; and (3) recently discovered agents causing gastroenteritis; Campylobacter jejuni bacteria and Norwalk Agent viruses. These organisms could not be specifically identified by methods used on this project. Of necessity, emphasis has been placed on more general microbiological assays which provide indication of potential contamination.

In water microbiology, an indicator organism is defined as a microorganism whose presence is evidence of contamination. From this concept, different groups of bacteria associated with feces have been suggested as possible indicators of the presence of many of the previously described pathogens in potable water. The coliform group is the most common indicator used today to determine sanitary water quality. The coliform group of bacteria, defined as gram negative, non-sporing bacilli which are capable of fermenting lactose with the production of acid and gas within 48 hours at 35°C, is the primary indicator of fecal contamination.

Historically, determining microbial water quality has meant assessing the potential of water to transmit diseases. When total coliforms were first adopted as the basic biological test of potable water quality in 1914 by the U.S. Public Health Service, the main concern was waterborne transmission of bacterial diseases such as typhoid fever and cholera. The mass of data collected since then has shown that the absence of coliforms in a conventionally treated water supply is good evidence that the supply is safe from these pathogens provided that the raw water is not taken from a highly contaminated source. Subsequent discovery of viruses and parasites in water has raised questions as to whether the absence of coliforms in a water supply assures the absence of other microbial pathogens. Although there is evidence that some viruses and parasites may survive longer in water and be more resistant to chlorine disinfection than coliforms, the use of the total coliform group as an indicator of microbiological quality has been retained since 1914 in subsequent Public Health Service regulations and the 1975 National Interim Primary Drinking Water Regulations (NIPDWR) as the sole microbiological criterion for potable water.

Total and fecal coliform bacteria and total bacterial standard plate count (SPC) tests were conducted on finished waters, using techniques described in Chapter 4 (Section 2). Bacterial counts such as the SPC test are indicative of the overall bacteriological quality of water.

An additional microbiological parameter assayed at the finished water sites was endotoxin, the significance of which is discussed later in this section.

## Microbiological Parameters

### OVERVIEW

Table 9.6-2 shows statistical summaries of monitoring results at the finished water sites. Each of these parameters is discussed in further detail in the sections which follow.

### TOTAL COLIFORMS

The maximum contaminant level (MCL) in the NIPDWR when using the Most Probable Number total coliform technique is based on the number of positive confirmed portions detected during an official surveillance period, usually one per month. When five replicate, 10 ml portions are inoculated, the MCL is exceeded if any of the following results occur, with sampling frequencies as specified by the regulations:

- >10 percent positive portions are detected in one month.
- >three positive portions are detected in more than one sample when less than twenty samples are examined in one month.
- >three positive portions in more than 5 percent of the samples are detected when twenty or more samples are examined in one month.

As previously mentioned, compliance with the MCL most often indicates that a finished water is acceptable for potable use. However, most river water sources have less microbial contamination than the EEWTP blended influent. The MCL may not be an adequate indicator of finished water quality when the source water is highly contaminated. The National Research Council (NRC, 1982) recommended total coliform limits of less than 1/1000 ml at least 90 percent of the time and less than 1/100 ml at least 98 percent of the time for finished water treated from a highly contaminated source, with daily sampling recommended.

Quantification of total coliforms at levels below 2.0 MPN/100 ml is not possible with the Standard Methods MPN technique (five, ten milliliter portions). Because of the relative insensitivity of the method, low level differences in coliform levels between the EEWTP and the local finished waters would not be discernible, and comparison to criteria more stringent than the MCL (such as these recommended by the NRC) would not be feasible. For these reasons, a modification of the technique was utilized for finished water samples in order to increase the assay sensitivity. A high volume technique was utilized, as described in Chapter 4 of this report, which resulted in a lowest quantifiable value of 0.02/100 ml. In addition, the standard five tube, 10 ml method was applied to the EEWTP finished water samples to demonstrate compliance with the NIPDWR MCL.

# Microbiological Parameters

TABLE 9.6-2  
COMPARISON OF FINISHED WATERS  
MICROBIOLOGICAL PARAMETERS

Parameter	Units	EWTP					
		Phase IA	Phase IB	Phase IIA	WTP 1	WTP 2	WTP 3
Total Coliform (confirmed)	MPN/100 ml <sup>a</sup>	181/255 <sup>b</sup>	19/68	11/119	9/448	18/283	23/282
Geometric Mean/Spread Factor	(MCL-1) <sup>c</sup>	0.0314/3.22	0.006/3/35	—	—	—	—
Arithmetic Mean/Standard Deviation		—	—	—	—	—	—
Median/90 Percentile		0.020/0.140	<0.018/0.04	<0.018/<0.018	<0.018/<0.018	<0.018/<0.018	<0.018/<0.018
Fecal Coliform (confirmed)	MPN/100 ml	25/187	3/71	1/114	1/375	1/216	2/213
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		—	—	—	—	—	—
Median/90 Percentile		<0.018/0.020	<0.018/<0.018	<0.018/<0.018	<0.018/0.018	<0.018/0.018	<0.018/0.018
Standard Plate Count	Colonies/ml	58/258	16/75	29/112	81/432	116/274	125/271
Geometric Mean/Spread Factor		0.2/8.46	0.4/3.40	0.4/4.29	0.2/7.55	0.7/3.88	0.8/5.23
Arithmetic Mean/Standard Deviation		—	—	—	—	—	—
Median/90 Percentile		<1.0/2	<1.0/2.0	<1.0/2	<1.0/2	<1.0/4	<1.0/7
Salmonella	MPN/100 ml	0/10	0/3	0/7	0/21	1/15	0/15
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		—	—	—	—	—	—
Median/90 Percentile		<0.022/<0.022	<0.022/<0.022	<0.022/<0.022	<0.022/<0.022	<0.022/0.022	<0.022/<0.022
Endotoxin	ng/ml	9/9	1/1	—	10/10	3/3	4/4
Geometric Mean/Spread Factor		2.9/3.16	2.5/1.0	—	3.0/1.63	2.5/1.83	9.4/1.52
Arithmetic Mean/Standard Deviation		5.0/4.8	2.5/0.0	—	3.4/1.8	3.0/2.1	10.2/4.8
Median/90 Percentile		5.0/12.5	2.5/2.5	—	2.5/6.2	2.5/5.3	6.2/12.5
Viruses							
No. of Assays		11	15	30	24	23	21
No. of Positives		0	0	0	0	0	0
Parasites							
No. of Assays		15	4	7	19	22	22
No. of Positives		0	0	0	0	1d	0

- a. MPN based on number of positive tubes in the five-tube, three-dilution test (1000, 100, 10 ml) for EWTP finished water. Only one dilution (1000 ml) was assayed for WTP samples; therefore, 100 and 10 ml tubes were assumed to be negative for calculations of MPN with the same MPN table used for all sites.
- b. 181 = Number of Samples Above Detection Limit (For coliforms, a sample was above the detection limit if at least one tube was positive in any dilution); (typical).
- c. 255 = Number of Samples (typical).
- d. MCL depends on analytical technique and sampling; see text.
- e. 5 *Giardia* cysts identified; sample of 20 July 1981.



## Microbiological Parameters

### ALUM PHASE

#### Phase IA

A tabular comparison of the Phase IA finished water to the finished water from the three local plants in the MWA is provided in Table 9.6-3. EEWTP samples were collected between 16 March 1981 and 16 March 1982. The local plant results represent samples collected between 16 March 1981 through 1 February 1983.

Sixty-five percent of the Phase IA EEWTP finished water samples had at least one positive confirmed tube out of five, using one liter portions. This percentage of positives was eight times the highest percentage of positive samples detected at a local plant. In terms of the number of presumptive Lauryl Tryptose Broth (LTB) portions inoculated which confirmed in Brilliant Green Lactose Bile Broth (BGB), the EEWTP had the highest percentage (30%) followed by WTP2 (2.0%), WTP3 (2.0%), and WTP1 (0.4%).

Figure 9.6-1(a) shows the probability distribution of Phase IA total coliforms from the EEWTP finished water. The 90 and 98 percent values are 0.14 and 0.35/100 ml, respectively. The ninety percent value (1.4/1000 ml) exceeded the NRC recommendation. The overall MPN calculated from one liter portions (Table 9.6-3) was 0.035/100 ml. Overall MPNs at local WTPs were 17 to 88 times lower than the EEWTP.

Total coliforms in Phase IA EEWTP finished water, however, did not exceed the MCL. Out of 1,265 ten milliliter portions inoculated between 16 March 1981 and 16 March 1982, only fourteen (1.1%) were positive in confirmatory BGB.

A breakdown of EEWTP high-volume coliform analyses by portion size is shown in Table 9.6-4. The reason for the high number of positive confirmed portions is difficult to explain but becomes somewhat clearer when the coliform data is broken down by month as shown in Figure 9.6-2. Nearly sixty percent of all the Phase IA positive confirmed portions were detected during the first three and one-half months (16 March 1981 - 30 June 1981) of this operating period. The percentage of monthly positives is based on a total of 484 positive confirmed portions detected during Phase IA. The number of positive portions observed each month was divided by this number to determine the percentages in Figure 9.6-2. Between 16 March and 30 June 1981, 98 percent (81 out of 83) of the samples analyzed had one or more positive portions compared to 58 percent for the remainder of Phase IA (1 July 1981 -16 March 1982). In Phase IA, 45 percent of all positive samples occurred during these early months of operations.

Excluding the first three and one-half months, the probability distribution in Figure 9.6-1(b) shows 90 and 98 percentiles of 0.08 and 0.17, respectively. During this period, the 90th percentile value met the NRC recommended total coliform criteria for potable re-use.

# Microbiological Parameters

TABLE 9.6-3

## PHASE IA CONFIRMED TOTAL COLIFORMS COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP 1</u>	<u>WTP 2</u>	<u>WTP 3</u>
No. of Samples	255	448	283	282
No. of Positive Samples <sup>a</sup>	165	9	18	23
% Positive Samples	65	2.0	6.4	8.2
Overall MPN/100 ml <sup>b</sup>	0.035	0.0004	0.002	0.002
Median MPN/100 ml	0.02	<0.02	<0.02	<0.02
Geometric Mean MPN/100 ml	0.03	-- <sup>c</sup>	--	--
90% Less Than	0.14	<0.02	<0.02	<0.02
Maximum Value/100 ml	0.49	0.05	0.23	0.13

a. A positive sample was defined as having at least one positive confirmed coliform tube out of five replicate one liter portions.

b. The overall MPN is calculated by the number of positive confirmed portions from initial 1,000 ml presumptive LTB inoculations according to the formula:

$$\text{MPN/100 ml} = \frac{100}{X} \text{ Ln } \frac{N}{N-A}$$

where: X = 1000 ml/portion concentrated on a membrane filter as the LTB inoculant

N = Number of 1,000 ml portions inoculated

A = Number of confirmed positive BGB portions

c. At least 15 percent of the samples must be positive to use the EM algorithm for calculating the geometric mean.

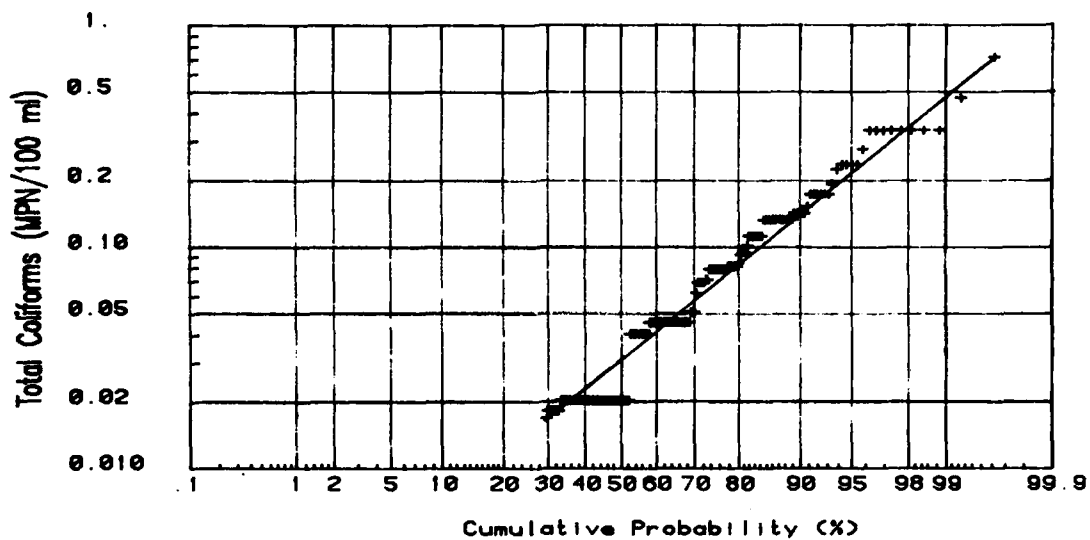
TABLE 9.6-4

## PHASE IA EEWTP FINISHED WATER CONFIRMED COLIFORMS - BY PORTION SIZE

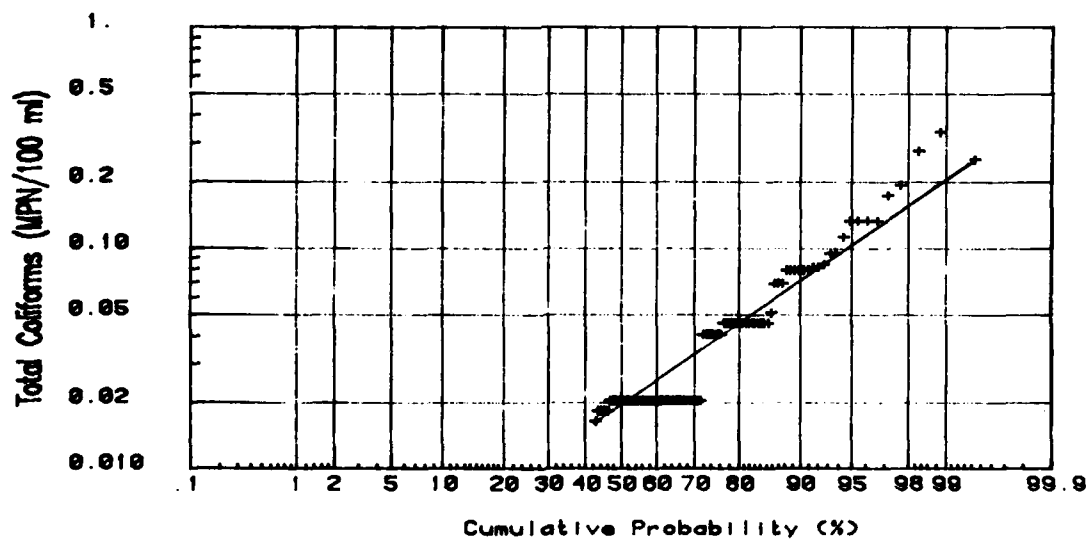
	<u>1,000 ML</u>	<u>100 ML</u>	<u>10 ML</u>
No. of Portions Inoculated in LTB	1,275	1,260	1,265
No. of Positive BGB Portions	379	91	14
% Positive BGB Portions <sup>1</sup>	30	7.2	1.1

<sup>1</sup> Percent positive confirmed portions were calculated by the following formula:

$$\% \text{ Positive} = \frac{\# \text{ Positive BGB Portions}}{\# \text{ Inoculated LTB Portions}} \times 100$$



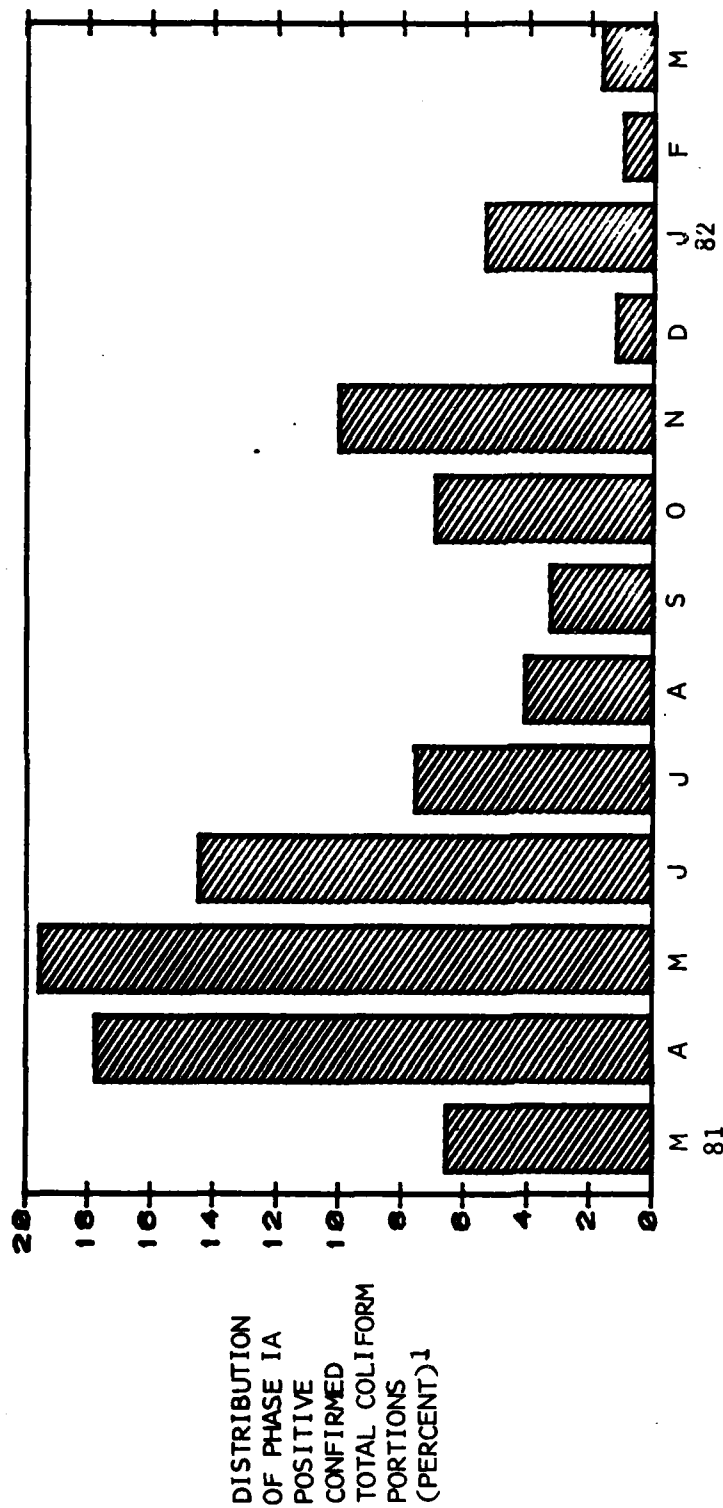
(a.) Total coliforms in EEWTP finished water (16 March 1981 to 16 March 1982 - Phase IA)



(b.) Total coliforms in EEWTP finished water (1 July 1981 to 16 March 1982 - Phase IA, excluding first 3 1/2 months.)

## TOTAL COLIFORMS IN EEWTP FINISHED WATER

FIGURE 9. 6-1



1. A total of 484 positive portions were detected. The number of positive portions in a month was divided by 484 to obtain the monthly percentage.

## MONTHLY DISTRIBUTION OF CONFIRMED TOTAL COLIFORM PORTIONS FROM PHASE IA EEWTP FINISHED WATER

FIGURE 9. 6-2

## Microbiological Parameters

In general, the high frequency of positive portions and samples detected during the first few months of EEWTP operation could have been due to low free residual chlorine levels chosen for final disinfection, a problem which was compounded by sporadic levels of ammonia entering the plant from the Blue Plains source. Also, start-up of operations was associated with numerous process alterations needed to stabilize plant performance. Details of Phase IA disinfection are found in Chapter 7.

### Phase IB Results

Phase IB total coliform samples were collected between 17 March 1982 and 6 July 1982 for EEWTP finished water. These results are compared to local WTP samples collected between 16 March 1981 and 1 February 1981 as shown in Table 9.6-5. Overall, the percentage of positive confirmed samples was much lower in Phase IB (30%) compared to Phase IA (65%). During the corresponding time periods in both phases (17 March to 6 July), 89 percent of the samples (77 out of 87) analyzed in IA were positive while 28 percent were positive in IB. However, this period includes the first few months of EEWTP operation in 1981 which had the unusually high number of positive portions and samples as described previously. A total of 68 EEWTP samples were analyzed during Phase IB. The last 68 samples in Phase IA were collected between 2 December 1981 and 16 March 1982. These samples yielded 32 percent positives which is much closer to the Phase IB percentage of thirty percent.

Ninety percent of the Phase IB EEWTP samples had total coliform levels less than or equal to 0.04/100 ml. This means the NRC (1982) criteria of less than 1/1,000 ml in at least 90 percent of samples was met. Also, because no individual sample had an MPN greater than 1.0/100 ml, the second criteria of less than 1/100 ml 98 percent of the time was also met (Figure 9.6-3(a)).

Table 9.6-6 shows the breakdown of Phase IB EEWTP confirmed total coliforms by portion size tested. No positive confirmed portions were detected in the 340 LTB portions inoculated with 10 ml of sample. Therefore, the MCL was always met in this phase of operations.

### LIME PHASE

Phase IIA treatment included final disinfection with ozone and residual disinfection with chloramination. Total coliform results are shown in Figures 9.6-3(b) and in Tables 9.6-7 and 9.6-8. These results pertain to samples collected after chloramination (finished water). EEWTP finished water samples were collected between 23 July 1982 and 1 February 1983. Results for local plants are combined for all three phases, 16 March 1981 through 1 February 1983.

A total of 585 LTB tubes were inoculated with 10 ml each of EEWTP finished water during Phase IIA. There were no confirmed BGB tubes detected in these samples (Table 9.6-7). The observed water quality differences between the EEWTP and the local WTPs is smallest during this phase (Table 9.6-8), with the percentage of positive confirmed samples in the EEWTP finished water lower in Phase IIA than in either of the previous two phases (Table 9.6-9).

# Microbiological Parameters

TABLE 9.6-5  
PHASE IB TOTAL CONFIRMED COLIFORMS  
COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples Assayed	68	448	283	282
No. of Positive Samples <sup>1</sup>	19	9	18	23
% Positive Samples	28	2.0	6.4	8.2
Median MPN/100 ml	<0.02	<0.02	<0.02	<0.02
Overall MPN/100 ml <sup>2</sup>	0.007	0.0004	0.002	0.002
90% Less Than	0.04	<0.02	<0.02	<0.02
Geometric Mean/100 ml	0.008	--3	—	—
Maximum Value/100 ml	0.23	0.05	0.23	0.13

1. A positive sample is one with at least one positive confirmed coliform tube out of five replicate one liter portions.
2. The overall MPN is calculated by the number of positive confirmed portions from the initial 1,000 ml high-volume presumptive LTB inoculations according to the formula:

$$\text{MPN/100 ml} = \frac{100}{X} \ln \frac{N}{N-A}$$

where: X = 1,000 ml/portion concentrated on a membrane filter as the LTB inoculant

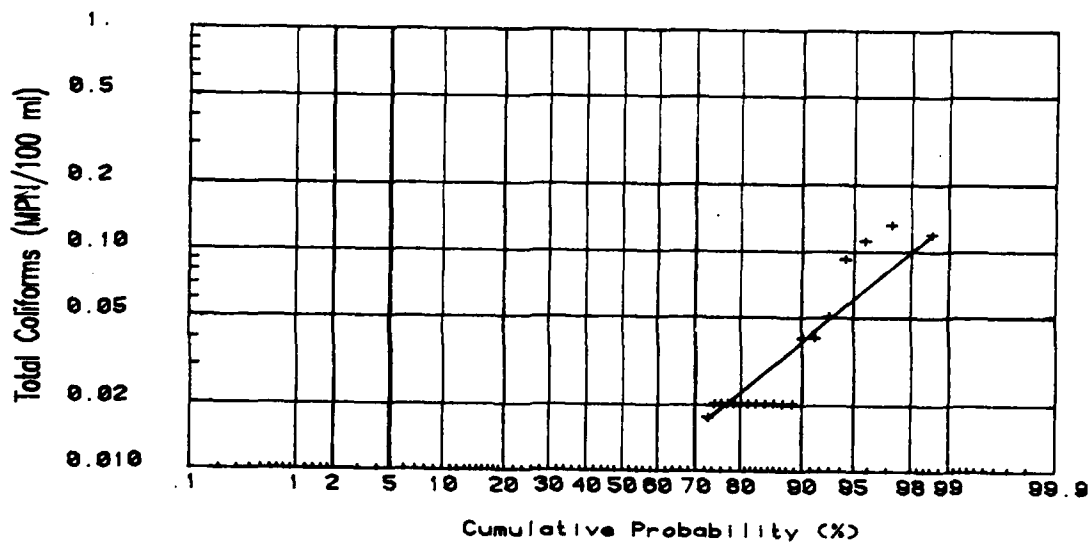
N = Number of 1,000 ml portions inoculated

A = Number of positive confirmed BGB tubes

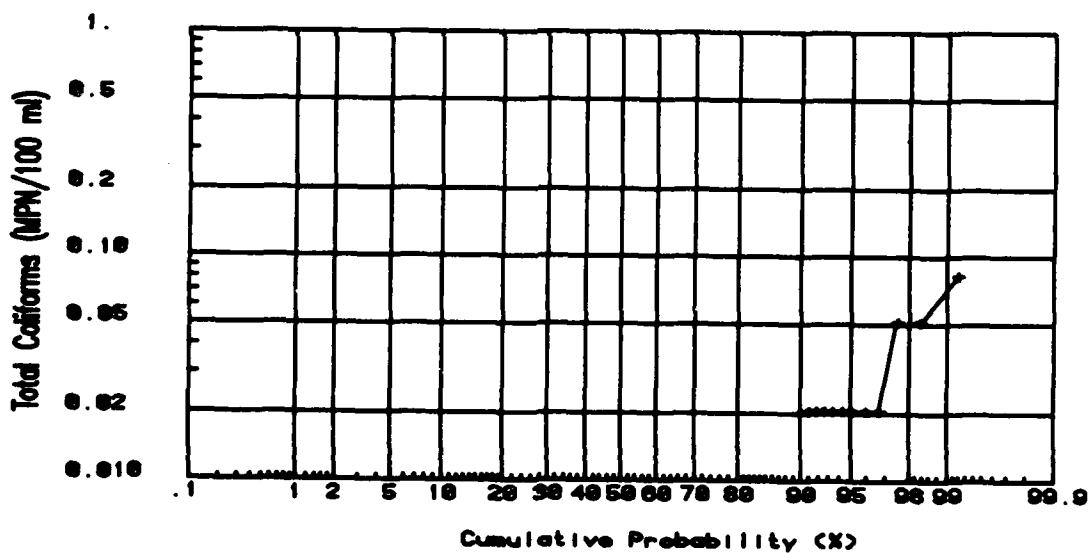
3. Geometric mean not calculated (less than 15 percent of samples quantified).

TABLE 9.6-6  
PHASE IB CONFIRMED TOTAL COLIFORMS - EEWTP  
FINISHED WATER SAMPLES BY PORTION SIZE

	<u>1,000 ml</u>	<u>100 ml</u>	<u>10 ml</u>
No. of LTB Tubes Inoculated	340	340	340
No. of Positive Confirmed BGB Tubes	24	4	0
% Positive BGB Tubes	7.1	1.2	0



(a) Total Coliforms in EEWTP Finished Water  
(17 March 1982 to 6 July 1982-Phase IB)



(b) Total Coliforms in EEWTP Finished Water  
(16 July 1982 to 1 February 1983 - Phase IIA)

**TOTAL COLIFORMS IN EEWTP FINISHED WATER  
(PHASES IB AND IIA)  
FIGURE 9. 6-3**

## Microbiological Parameters

TABLE 9.6-7  
PHASE IIA EEWTP FINISHED WATER CONFIRMED COLIFORMS  
BY PORTION SIZE

	<u>1,000 ml</u>	<u>100 ml</u>	<u>10 ml</u>
No. of Portions Inoculated in LTB	595	585	585
No. of Positive BGB Portions	13	2	0
% Positive BGB Portions <sup>1</sup>	2.2	0.3	0

1 Percent positive confirmed portions were calculated by the following formula:

$$\% \text{ Positive} = \frac{\# \text{ Positive BGB Portions}}{\# \text{ Inoculated LTB Portions}} \times 100$$

TABLE 9.6-8  
PHASE IIA TOTAL CONFIRMED COLIFORMS  
COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples Assayed <sup>1</sup>	119	448	283	282
No. of Positive Samples	11	9	18	23
% Positive Samples	9.2	2.0	6.4	8.2
Overall MPN/100 ml <sup>2</sup>	0.002	0.0004	0.002	0.002
Median MPN/100 ml	<0.02	<0.02	<0.02	<0.02
90% Less Than	<0.02	<0.02	<0.02	<0.02
Maximum Value/100 ml	0.08	0.05	0.23	0.13

1. A positive sample is defined as having at least one positive confirmed tube in five replicate one liter portions.
2. The overall MPN is calculated by the number of positive confirmed portions from the initial 1,000 ml high-volume presumptive LTB inoculations according to the formula:

$$\text{MPN/100 ml} = \frac{100}{X} \text{Ln} \frac{N}{N-A}$$

where: X = 1,000 ml/portion concentrated on a membrane filter as the LTB inoculant

N = Number of 1,000 ml portions inoculated

A = Number of positive confirmed BGB tubes



## Microbiological Parameters

TABLE 9.6-9  
CONFIRMED TOTAL COLIFORMS IN EEWTP  
FINISHED WATER

	Phase IA	Phase IB	Phase IIA (ozonated)	Phase IIA (finished)
Number of Samples	255	68	93	119
%Positive Samples	65	28	26	9.2
Overall MPN	0.035	0.007	0.008	0.002
Median MPN	0.02	<0.02	<0.02	<0.02
90% Less Than	0.14	0.04	0.05	<0.02

Table 9.6-9 includes total coliform results from the ozonated effluent (prior to chloramine addition) which indicate that chloramines provided additional disinfection after ozonation.

Phase IIA total coliform levels met the NAS recommended criteria for potable reuse. Ninety percent of the Phase IIA EEWTP finished water samples had levels less than 0.02/100 ml and no sample value was greater than 0.1 MPN/100 ml. The performance of ozone/chloramine disinfection reduced coliform levels to a point where the EEWTP finished water was consistently as good as the local WTPs on a daily basis.

As a quality control check, Phase IIA positive BGB tubes from the EEWTP ozonated effluent, EEWTP finished water and the local plants were carried through the completed MPN test. Broth cultures were streaked on Eosin Methylene Blue agar plates and isolated typical (green sheen or nucleated) coliform colonies were transferred to fresh LTB tubes. The same colony transferred to LTB was streaked on a nutrient agar slant for identification in the API-20E system. Fifty-six of the sixty-one BGB tubes submitted to the completed test were positive in the LTB verification tubes. The frequency of false positive confirmed tubes was only eight percent. Identifications of thirty-five of the isolated verified coliforms are given in Table 9.6-10.

## Microbiological Parameters

TABLE 9.6-10  
VERIFIED COLIFORM IDENTIFICATIONS—PHASE IIA

	Number of Isolates Identified				
	EEWTP Post- Ozone	EEWTP Finished	WTP1	WTP2	WTP3
<u>Enterobacter cloacae</u>	7	1	—	—	—
<u>Enterobacter aerogenes</u>	— <sup>a</sup>	1	—	—	—
<u>Enterobacter</u>					
<u>agglomerans</u>	1	—	—	—	1
<u>Klebsiella ozaenae</u>	1	2	—	—	—
<u>Klebsiella oxytoca</u>	2	1	1	4	—
<u>Klebsiella pneumoniae</u>	1	1	—	—	—
<u>Citrobacter freundii</u>	1	3	—	2	—
<u>Escherichia coli</u>	2	—	—	—	—
<u>Aeromonas hydrophila</u>	2	—	—	—	—
<u>Pasteurella aerogenes</u>	—	1	—	—	—

a. Not Found

Encapsulated species of Enterobacter and Klebsiella account for sixty-nine percent of the identified coliforms. Capsular material surrounding the cell wall may make these bacteria more resistant to disinfection and may have caused the observed breakthrough.

### FECAL COLIFORMS

A subset of the total coliform group is the fecal coliforms which can grow at incubation temperatures at or above the internal mammalian body temperature. The most common fecal coliforms, E. coli and Klebsiella sp., can be routinely isolated from the feces of warm blooded animals. Non-fecal coliforms, predominantly Enterobacter sp., are more commonly associated with natural vegetation and soils and usually fail to grow at 44.5°C, the fecal coliform test incubation temperature. In the MPN test, positive presumptive total coliform tubes were simultaneously transferred to a total coliform confirmatory growth medium (BGB) which was incubated at 35°C and to the fecal coliform E.C. Broth which was incubated at 44.5°C in a water bath. The presence of fecal coliforms in water is more definitive evidence than the presence of total coliforms that the water has been contaminated recently by fecal wastes, either of human or animal origin.

### ALUM PHASE

#### Phase IA Results

Table 9.6-11 summarizes fecal coliform results from EEWTP and local treatment plant finished waters. EEWTP samples were collected between

## Microbiological Parameters

16 March 1981 and 16 March 1982. Local WTP samples were collected between 16 March 1981 and 1 February 1983.

TABLE 9.6-11  
PHASE IA FECAL COLIFORMS  
COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	187	375	216	213
No. of Positive Samples <sup>1</sup>	25	1	1	2
% Positive Samples	13	0.3	0.5	0.9
Median MPN/100 ml	<0.02	<0.02	<0.02	<0.02
90% Less Than	0.02	<0.02	<0.02	<0.02
Maximum Value/100 ml	0.08	0.02	0.02	0.02

1. A positive sample was defined as having at least one positive E.C. portion.

Fecal coliform levels in the four finished waters were very low, ranging between 0.02 to 0.08/100 ml. The EEWTP had the highest percentage of positive samples (13%), although 19 of the 25 positive EEWTP samples were collected during the first few months of EEWTP operations (16 March 1981 - 30 June 1981), the period during which very high numbers of positive total coliform samples were observed, as discussed.

### Phase IB Results

The reduction in the percentage of positive EEWTP fecal coliform samples from Phase IA (13%) to Phase IB (4.2%) was very similar to the Phase IB reduction of total coliforms previously described. Table 9.6-12 summarizes Phase IB fecal coliform results. EEWTP samples were collected between 17 March 1982 and 6 July 1982. Local plant samples were collected between 16 March 1981 and 1 February 1983.

TABLE 9.6-12  
PHASE IB FECAL COLIFORMS  
COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP 1</u>	<u>WTP 22</u>	<u>WTP 3</u>
No. of Samples	71	375	216	213
No. of Positive Samples <sup>1</sup>	3	1	1	2
% Positive Samples	4.2	0.3	0.5	0.9
Median MPN/100 ml	<0.02	<0.02	<0.02	<0.02
90% Less Than	<0.02	<0.02	<0.02	<0.02

1. A positive sample was defined as having at least one positive E.C. portion.

## Microbiological Parameters

### LIME PHASE

Only one EEWTP sample was positive in the E.C. fecal coliform test during Phase IIA (Table 9.6-13). Local WTPs had very few fecal coliform isolations. The local plant results in Table 9.6-13 were calculated from samples collected between 16 March 1981 and 1 February 1983. EEWTP samples were collected and analyzed between 23 July 1982 and 1 February 1983.

TABLE 9.5-13  
PHASE IIA FECAL COLIFORMS  
COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	114	375	216	213
No. of Positive Samples <sup>1</sup>	1	1	1	2
%Positive Samples	0.9	0.3	0.05	0.9
No. of Positive E.C. Portions	1	1	1	2
Median MPN/100 ml	<0.02	<0.02	<0.02	<0.02
90% Less Than	<0.02	<0.02	<0.02	<0.02
Maximum Value	0.02	0.02	0.02	0.02

1. A positive sample was defined as having at least one positive E.C. portion.

### STANDARD PLATE COUNT

The standard plate count (SPC) represents the number of bacteria which grow and form colonies in a chemically defined agar medium at a specific incubation temperature and time. The standard plate count in Standard Methods was used in this project. A known volume of water, 1 ml for finished water samples, was mixed into 10 ml liquified SPC agar maintained at 45°C, poured into a petri dish and incubated for 48 hours at 35°C. This is called the pour plate method. Only heterotrophic bacteria which can grow on top of or within the SPC agar layer will form visible colonies which are then counted to determine the number of bacteria in 1 ml of sample.

### ALUM PHASE

#### Phase IA Results

The EEWTP and local WTPs were sampled from 16 March 1981 through 16 March 1982 and 16 March 1981 through 1 February 1983, respectively, as shown in Table 9.6-14. Most of the statistical parameters for the local plants were higher than the EEWTP. WTP2 and WTP3 had a higher percentage of positive samples and higher estimated geometric mean. WTP1 had a higher maximum SPC value than the EEWTP. These results are shown graphically in Figure 9.6-4(a). As indicated in Table 9.6-15, the estimated geometric mean

## Microbiological Parameters

in the EEWTP finished water was significantly lower than the highest estimated means at a local plant.

Overall, however, all four finished water sites had low standard plate counts. Ninety percent of the WTP3 samples had SPC levels less than or equal to 7.0/ml. The 90th percentiles in the EEWTP and WTP1 samples were 2.0/ml. SPC values were always less than the 500/ml level recommended by the NAS (1977) for potable water. The NRC (1982) recommendation for potable reuse is less than 100/ml based on daily sampling. This value was exceeded three times (1.2%) at the EEWTP and twice (0.5%) at WTP1.

TABLE 9.6-14

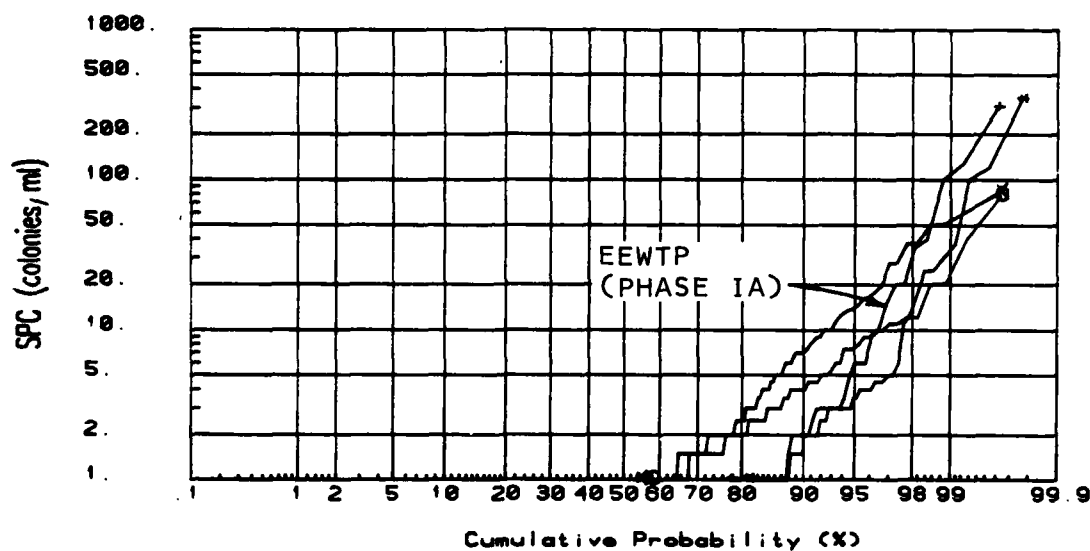
### PHASE IA STANDARD PLATE COUNT - COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	258	432	274	271
No. of Positive Samples	58	81	116	125
% Positive Samples	22	19	42	46
Geometric Mean SPC/ml	0.2	0.2	0.7	0.8
Median SPC/ml	<1.0	<1.0	<1.0	<1.0
Maximum SPC/ml	300	340	78	83
90% Less Than	2.0	2.0	4.0	7.0
No. of Samples $\geq 100$ /ml	3	2	0	0

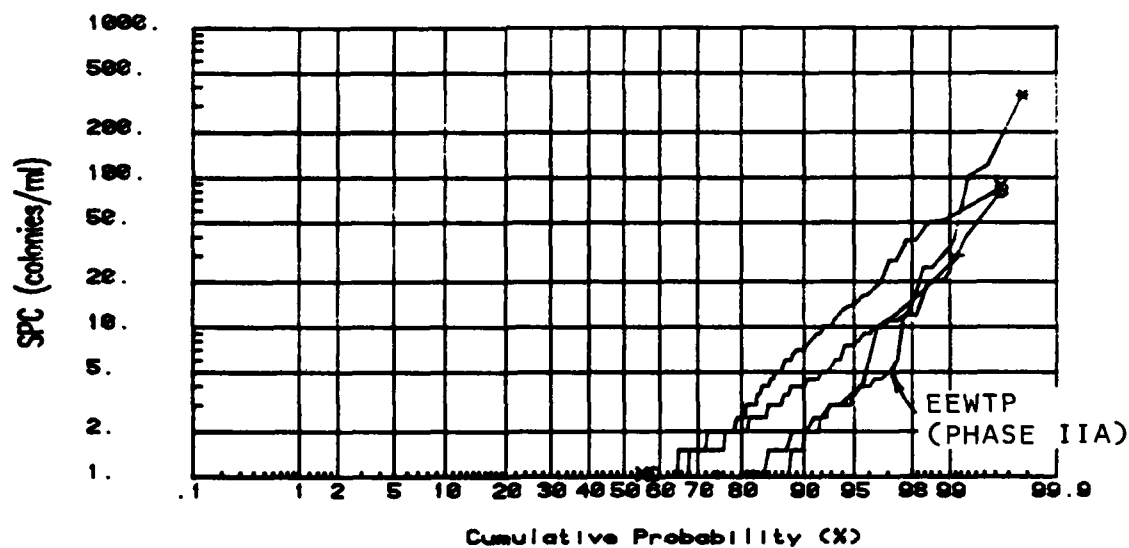
TABLE 9.6-15

### APPLICATION OF THE T-TEST EVALUATION FOR SIGNIFICANT DIFFERENCES IN GEOMETRIC MEANS FOR STANDARD PLATE COUNT IN FINISHED WATERS

<u>Highest Geom Mean at Local WTP</u>	<u>Phase of EEWTP Operation</u>	<u>Geom Mean at EEWTP</u>	<u>No. of Degrees of Freedom</u>	<u>t</u>	<u>t-statistic for 0.5 Signif. Level</u>	<u>Signif. Difference</u>
0.800	Alum-IA	0.200	264.6	-8.32	1.64	EEWTP<WTP3
	Alum-IB	0.400	124.5	-4.00	1.64	EEWTP<WTP3
	Lime-IIA	0.400	167.8	-4.07	1.64	EEWTP<WTP3



(a) SPC in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) SPC in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**STANDARD PLATE COUNT ( SPC ) IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 6-4**

## Microbiological Parameters

### Phase IB Results

Phase IB EEWTP results (Table 9.6-16) are very similar to the Phase IA results in Table 9.6-14. As shown in Table 9.6-16, the estimated geometric mean level was again significantly below the highest geometric mean level estimated for a local WTP. The major difference is that the maximum SPC in EEWTP Phase IB finished water is 14/ml compared to 300/ml in Phase IA. The 90th percentile value, 2.0/ml, is the same in both phases. The NAS and NRC recommended SPC levels were always met in Phase IB.

TABLE 9.6-16

#### PHASE IB STANDARD PLATE COUNT - COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP 1</u>	<u>WTP 2</u>	<u>WTP 3</u>
No. of Samples	75	432	274	271
No. of Positive Samples	16	81	116	125
% Positive Samples	21	19	42	46
Geometric Mean SPC/ml	0.4	0.2	0.7	0.8
Median SPC/ml	<1.0	<1.0	<1.0	<1.0
Maximum SPC/ml	14	340	78	83
90% Less Than	2.0	2.0	4.0	7.0
No. of Samples $\geq 100$ /ml	0	2	0	0

### LIME PHASE

Standard plate count bacteria were present in Phase IIA finished water at very low levels (Table 9.6-17). WTP2 and WTP3 had higher geometric mean and 90 percentile values than the EEWTP finished water, with NAS and NRC recommended SPC levels always met by the Phase IIA EEWTP finished water.

TABLE 9.6-17

#### PHASE IIA STANDARD PLATE COUNT COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	112	432	274	271
No. of Positive Samples	29	81	116	125
% Positive Samples	26	19	42	46
Geometric Mean SPC/ml	0.4	0.2	0.7	0.8
Median SPC/ml	<1.0	<1.0	<1.0	<1.0
Maximum SPC/ml	29	340	78	83
90% Less Than	2.0	2.0	4.0	7.0
No. of Samples $\geq 100$ /ml	0	2	0	0

## Microbiological Parameters

### SALMONELLA

Salmonellae belong to the same family (Enterobacteriaceae) as coliform bacteria. They differ from the coliform group by their inability to ferment lactose.

Salmonella typhi causes typhoid fever, an acute infectious disease primarily adapted to man. The typical symptoms are characterized by an acute gastroenteritis starting 4 to 48 hours after ingestion and usually subsiding within a week. Typhoid fever is endemic in the U.S. and has a tendency to produce permanent carrier states. S. typhimurium, S. heidelberg, S. newport, S. infantis, S. enteritidis, and S. st. paul are the most common isolated types in the U.S. which cause a similar although milder disease in humans. The carrier state of greater than 1 year is rare for these organisms.

Salmonella multiply in the intestine and are excreted in feces by individuals with enteric fever or food poisoning. Among the population, however, a small proportion of healthy individuals (carriers) are excreting these organisms intermittently or continuously. Water is a relatively common vehicle of infection, especially outside the U.S. and Western Europe. Today, in the U.S. infection more often results from contaminated foods than from water. However, polluted processing water has been an initial source of contamination.

Traditional measures of microbial water quality cannot always predict the potability of water. One of the best known outbreaks of Salmonellosis, caused by Salmonella typhimurium, occurred in Riverside, California in 1965. This incident is of particular interest because coliforms were not isolated from the distribution water. Eventually the agent was traced to contaminated well waters, but epidemiologists were never able to establish how the well water became contaminated with Salmonella typhimurium. Seven different strains of Salmonella have been isolated from treated and untreated drinking water in 11 of 2,128 water samples in France. Counts of E. coli, coliforms and streptococci levels met bacteriological standards in nine of these eleven samples (Sinegre et al, 1975).

#### ALUM PHASE

Salmonella bacteria were not isolated from any of the thirteen EEWTP finished water samples collected and analyzed during Phases IA and IB (Table 9.6-18). The local plant samples were collected between 16 March 1981 and 1 February 1983. One sample from WTP2 was positive for Salmonella (0.02/100 ml). This sample was collected on 1 November 1982.

During Phases IA and IB Salmonella organisms were isolated from eight of twelve (67%) Blue Plains nitrified effluent samples, two of twelve (17%) Potomac River estuary samples and six of seven (86%) EEWTP blended influent samples. The EEWTP processes removed these bacteria to below 0.02/100 ml, the minimum quantifiable limit using high-volume 1,000 ml portions.



## Microbiological Parameters

TABLE 9.6-18  
PHASE IA AND IB SALMONELLA ISOLATIONS  
COMPARISON OF FINISHED WATER

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	13	21	15	15
No. of Positive Samples <sup>1</sup>	0	0	1	0

1. A positive sample was defined as having at least one Salmonella isolation among the five replicate one liter portions.

### LIME PHASE

Seven Salmonella samples were collected at the EEWTP finished water site during Phase IIA. Each sample consisted of five replicate one liter portions which were processed through the modified, high-volume MPN test. Salmonella species were not isolated from any of the thirty-five portions examined.

### ENTERIC VIRUSES

Viruses are intracellular parasites which possess no metabolic activity while outside a host cell. These microbes have a protein coat (capsid) which may have a lipid-like envelope. The capsid protects the double or single strand of nucleic acid which is either RNA or DNA. There have been viruses discovered for almost every type of living cell and organism. However, due to infection mechanisms which are site specific, many viruses have a narrow range of hosts. Enteric viruses multiply in the gastrointestinal tract and are shed in feces.

More than 100 enteric viruses are known to be excreted in human feces, and these are summarized in Table 9.6-19. Only two of these enteric viruses, Hepatitis Virus A and Norwalk Agent have been implicated by rigorous epidemiological evidence to be transmitted by the water route. There are some indications of possible waterborne infections for poliovirus (Mosely, 1967), adenoviruses (Foy, 1968), and coxsackieviruses (Hawley, 1973).

Hepatitis A and Norwalk Agent have yet to be cultivated in the laboratory for practical use in water and wastewater assay procedures. No routine recovery and detection methods exist for these viruses which could be employed in this project. Other enteric viruses which can be detected might serve as indicators of the presence of Hepatitis A and Norwalk Agent, although no correlation has been demonstrated.

Conventional water treatment can be expected to remove between five and eight logs of virus with the major reduction occurring at the disinfection step. However, there have been reports of isolating viruses from drinking water in a number of nations (Hoehn et al, 1977; Payment, 1981; Sekla, 1980). Detailed

## Microbiological Parameters

analysis of associated treatment trains have not been reported, so it is difficult to determine the reasons for their occurrence.

### ALUM PHASE

Enteric viruses were not detected in any of the twenty-six EEWTP finished water samples concentrated and assayed during Phases IA and IB. Twenty-four concentrates were analyzed on BGM and MA 104 cell lines, two were analyzed on BGM and RD cells. A total of 68 local treatment plant samples were concentrated and assayed between 16 March 1981 and 15 February 1983. None of these concentrates yielded positive enteric virus isolations (Table 9.6-20) on any of the three cell lines.

During Phases IA and IB, viruses were detected in the two EEWTP influents and the EEWTP blend water. Combining all the Phase IA and IB results from these sites, a total of 17 of 38 samples concentrated were positive for viruses in at least one cell line. Six of the 38 samples were assayed on BGM and RD cells, the remaining 32 on BGM and MA 104 cells. A complete tabulation of enteric virus data is found in Appendix H, Table H-7.

### LIME PHASE

All thirty EEWTP finished water samples concentrated and assayed between 17 July 1982 and 9 February 1983 (Phase IIA) were negative on MA 104 and BGM cells. A total volume of 26,114 gallons was filtered through the virus concentrator. Virus concentrates equivalent to approximately 13,000 gallons of finished water were applied to the cell monolayers. Viruses were detected in the EEWTP blended influent during Phase IIA monitoring. Table 9.6-21 summarizes viruses entering the plant in the blended influent. Fifty percent of the 32 assays were positive in at least one of the cell lines.

All of the sixty-eight local WTP samples assayed during the entire project were negative for enteric viruses (Table 9.6-20).

TABLE 9.6-19  
HUMAN EXCRETED VIRUSES

Virus Group	Family	Size and Composition	Types	Diseases or Symptoms Caused
Enterovirus	Picornaviridae	About 20-35 nm diameter Single-stranded RNA in a protein shell	3 24 6 34 4 1	Poliomyelitis, meningitis, fever Herpangina, respiratory disease, meningitis, fever Myocarditis, congenital heart anomalies, meningitis, respiratory disease, pleurodynia, rash, fever Meningitis, respiratory disease, rash, diarrhea, fever Meningitis, encephalitis, respiratory disease, acute haemorrhagic conjunctivitis, fever Infectious hepatitis
Hepatitis A virus	Picornaviridae	About 24-29 nm diameter Single-stranded RNA	>30	Respiratory disease, eye infections
Adenovirus	Adenoviridae	About 70-80 nm diameter Double-stranded DNA in a protein shell	3	Not clearly established
Reovirus	Reoviridae	About 75 nm diameter Double-stranded RNA in a double protein shell	?	Vomiting and diarrhea
Rotavirus	Reoviridae	About 70 nm diameter Double-stranded RNA in a double protein shell	?	Vomiting and diarrhea
Calicivirus	(Unknown)	About 35-40 nm diameter Single-stranded RNA in a protein shell	?	Common cold
Coronavirus	Coronaviridae	Between 20 and 220 nm diameter Pleomorphic with petal-shaped projections Single-stranded RNA in a protein shell and lipid envelope	?	Vomiting and diarrhea
Norwalk Agent and other small round viruses	(Unknown)	About 20-35 nm diameter	?	Vomiting and diarrhea

? = Unknown

## Microbiological Parameters

TABLE 9.6-20  
PHASE IA AND IB EEWTP ENTERIC VIRUS ISOLATIONS  
COMPARISON OF FINISHED WATERS<sup>1</sup>

	<u>EEWTP</u>	<u>WTP 1</u>	<u>WTP 2</u>	<u>WTP 3</u>
No. of Samples	26	24	23	21
Total Volume Concentrated (Gallons)	25,444	19,375	19,025	14,683
Equivalent Volume Applied to Cells (Gallons) <sup>2</sup>	12,722	9,688	9,513	7,342
No. of Positive Samples	0	0	0	0

1. Isolates for local plants include data for two years of monitoring.
2. Approximately one-half of the sample concentrate was applied to the cell monolayers.

TABLE 9.6-21  
ENTERIC VIRUSES IN EEWTP BLENDED INFLUENT  
Cell Line

	<u>BGM</u>	<u>MA 104</u>
Number of Samples	32	32
Number of Positive Samples	16	14
Range MPNCU <sup>1</sup> /gal	ND to >0.24	ND to >0.23

1. MPNCU = Most probable number of cytopathic units.

## PARASITES

The most important protozoa and helminth parasites transmitted to humans through water were monitored during the project. The diseases caused by these parasites are listed in Table 9.6-22.

## PHASE IA AND IB RESULTS

Phase IA and IB results are combined in Table 9.6-23. Local WTP samples were collected between 16 March 1981 and 14 February 1983. Table 9.6-23 includes the total gallons filtered and the equivalent gallons microscopically examined when results from all individual assays are combined. The equivalent volume examined during a single assay is a function not only of the volume filtered, but also of the portion of the concentrated residue (reconcentrated eluate pellet) which was examined. The equivalent volume was calculated by dividing the gallons filtered by the ratio of the total pellet volume to the pellet volume examined. Several cases occurred where individual sample volumes were not recorded, so that this value and the equivalent volume assayed could not be computed into the totals. In several instances the sample volume was known but the equivalent volume was not recorded. The volumes in columns two and

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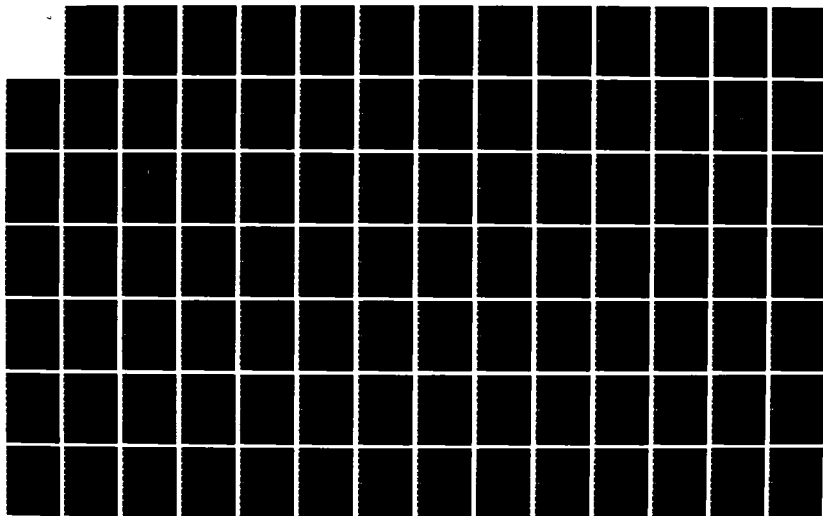
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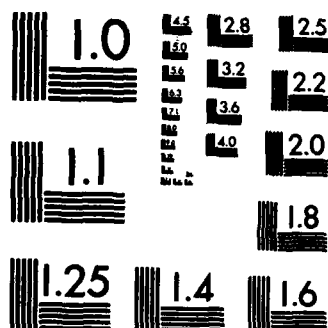
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## Microbiological Parameters

three were calculated from assays with recorded volumes; because volumes were not always recorded, these totals are slightly lower than the actual volumes concentrated and examined. The number of assays in the first column of the table includes those with unknown filtered volumes or unknown equivalent volumes examined.

# Microbiological Parameters

TABLE 9.6-22  
POTENTIAL WATERBORNE PARASITES

<u>Organism</u>	<u>Host, Habitat Transmission</u>	<u>Associated Disease</u>
<b>Protozoa</b>		
<u>Giardia lamblia</u>	Host: Man and certain animals (beavers). Transmission: Ingestion of cysts (contaminated water, food) Worldwide distribution	Variety of intestinal symptoms, intermittent diarrhea
<u>Entamoeba histolytica</u>	Host: Man. Transmission: Ingestion of cysts (contaminated water, food) Worldwide distribution	Mild abdominal discomfort to chronic dysentery
<u>Acanthamoeba</u>	Host: Man. Habitat: Free-living in soils and stagnant water. Transmission: Ingestion of cyst	Human pathogenicity uncertain. Associated with meningoencephalitis
<u>Naegleria gruberi</u>	Host: Man. Habitat: Free-living in soils and water. Transmission: Via nasal mucosa and the olfactory bulbs when swimming or playing in water	Pathogenic for man. Amoebic meningoencephalitis
<b>Helminths</b>		
<u>Ascaris lumbricoides</u>	Host: Man. Habitat: Soil and contaminated water. Transmission: Ingestion of egg. Worldwide distribution	Fever, allergic reactions, pulmonary symptoms, pneumonia
<u>Hookworm (Ancylostoma duodenale)</u>	Host: Man and select animals. Habitat: Soil and contaminated water. Transmission: Ingestion of fertile egg or larvae. Common in all hot countries between 40°N and 30°S	Anemia, weakness, anorexia, eosinophilia, abdominal discomfort
<u>Trichuris trichiura</u>	Host: Man. Transmission: Ingestion of eggs from contaminated water or dirty hands (soil). Worldwide distribution	Abdominal pain, headache, anorexia, weight loss, loss of appetite



## Microbiological Parameters

TABLE 9.6-23  
PHASE IA AND IB PARASITE RESULTS

	<u>No. Samples Assayed</u>	<u>Total Volume Filtered (Gallons)</u>	<u>Total Equivalent Volume Examined (Gallons)</u>	<u>No. of Parasites Detected</u>
EEWTP	19	12,582 (3) <sup>a</sup>	2,469 (5) <sup>a</sup>	0
WTP1	19	10,222 (2)	1,970 (4)	0
WTP2	22	8,275 (2)	2,607 (4)	5 <sup>b</sup>
WTP3	22	9,819 (2)	2,422 (3)	0

- a. Number in parenthesis indicates the number of assays with unknown volumes. Subtract this number from Column 1 to determine the number of assays used to calculate volume filtered and volume examined.
- b. The five parasites were detected in a single sample collected and concentrated 20 July 1981. All five parasites were identified as Giardia lamblia cysts.

Five Giardia cysts were identified in a WTP2 finished water sample concentrated on 20 July 1981. The volume filtered was not recorded. No other finished water sites were positive for the seven parasites listed in Table 9.6-23. Numerous larval worms were observed occasionally at all four sites. These larvae could not be identified.

### PHASE IIA RESULTS

Parasites were not detected in the seven EEWTP samples concentrated between 16 July 1982 through 14 February 1983. A total volume of 2,262 gallons was concentrated and an equivalent volume of 1,063 gallons examined microscopically for the presence of parasites. Local WTP results are summarized in Table 9.6-23 for the entire monitoring program (16 March 1981 through 14 February 1983). Five Giardia cysts were detected in a single sample from WTP2 (Phase IA). This was the only finished water isolation observed during the project.

### ENDOTOXIN

The Limulus Amoebocyte Lysate (LAL) assay for endotoxin quantification was developed by Levin and Bang who observed that in vitro coagulation of amoebocytes from the horseshoe crab, Limulus polyphemus, was mediated by gram negative bacterial endotoxins. This technique detects the lipopolysaccharide (LPS = endotoxin) of gram negative bacterial cell envelopes. Most gram negative bacteria possess LPS, whereas gram positive bacteria do not generally give a positive LAL test. LPS are also constituents of the outer cell wall of

## Microbiological Parameters

Cyanobacteria (blue-green algae). Viral RNA has also been shown to give a positive LAL test.

The in vitro endotoxin test has possible utility for the examination of drinking waters. The occurrence of LPS in drinking water has been studied in light of numerous cases of nosocomial endotoxemia suspected to have originated from the presence of LPS in drinking water. The ingestion of LPS may be responsible for some waterborne disease outbreaks (gastroenteritis) presently classified as "of unknown etiology".

### PHASE IA RESULTS

Table 9.6-24 summarizes Phase IA endotoxin results. Grab samples from local WTPs were collected between 16 March 1981 and 7 February 1983. WTP3 samples had the highest average, median and geometric mean endotoxin concentrations. WTP3 also had the highest geometric mean and 90 percentile SPC values among the local plants. In general, the low levels found in all of the finished waters are not considered capable of causing pyrogenic reactions, gastroenteritis or other disease symptoms when ingested, and are not of significant health concern.

TABLE 9.6-24  
PHASE IA ENDOTOXIN RESULTS - COMPARISON OF FINISHED WATERS

	<u>EEWTP</u>	<u>WTP1</u>	<u>WTP2</u>	<u>WTP3</u>
No. of Samples	9	10	3	4
Arithmetic Mean (ng/ml)	5.0	3.4	3.0	10.2
Geometric Mean (ng/ml)	2.9	3.0	2.5	9.4
Median Value (ng/ml)	5.0	2.5	2.5	6.2

### PHASE IB RESULTS

Only one EEWTP endotoxin sample was analyzed in Phase IB. The endotoxin concentration was 2.5 ng/ml.

### PHASE IIA RESULTS

Two EEWTP finished water samples were analyzed in Phase IIA. The concentrations were 1.4 and 6.2 ng/ml.

## SUMMARY

Two pathogenic microbiological organisms, Salmonella and enteric viruses, were detected frequently in the EEWTP influent sources and blend, but neither one was detected in the EEWTP finished water samples. One Salmonella isolate was identified from a MWA water treatment plant sample during the project. Parasitic organisms were not detected in any EEWTP finished water samples. Giardia cysts were detected in only one local WTP sample; all other WTP samples were negative for parasites.

## Microbiological Parameters

The EEWTP finished water samples always met the NIPDWR total coliform maximum contaminant level. Using a more sensitive high-volume assay than the one used for MCL compliance, it was demonstrated that total coliforms were higher in the EEWTP finished water than the local WTPs, both in terms of percentage of positive samples as well as most other statistical parameters evaluated. Total coliform breakthrough at the EEWTP may have been caused by encapsulated coliform strains which could be more resistant to disinfection, although identifications were only available for the Phase IIA ozone process. Fecal coliform levels were low at all finished water sites. In general, there was very little difference between fecal coliform concentrations at the EEWTP and the local WTPs, compared to the differences observed for total coliforms. The first several months of Phase IA operation represent an exception to this, with a notably higher percentage of detectable levels, although all were at MPNs less than 0.08/100 ml.

Standard plate count bacteria levels were low at all four finished water sites. Estimated geometric mean and median values were always less than 1 colony/ml. EEWTP finished water results, such as the percentage of positive samples and geometric mean concentration, were lower than the highest local WTP in each phase of operation.

Thus, the MPN for total coliforms was the only monitored microbiological parameter which indicated potential concern with respect to the suitability of EEWTP finished water for drinking. Despite initially frequent positives during Phase IA, however, frequency distributions (Figures 9.6-1(b), 9.6-3(a), and 9.6-3(b)) do indicate that the NRC criteria for potable re-use (NRC, 1980) could be met by all the process combinations utilized. It is apparent that careful control of the disinfection process is required, as previously discussed in Chapters 7 and 8.



## SECTION 7

### ORGANIC PARAMETERS

#### INTRODUCTION

Increasing numbers and types of organics are identified in drinking water supplies, and more sophisticated and comprehensive analytical measurements are coming into common use. Corresponding efforts are being made in health effects research, as discussed in Chapter 1. The current emphasis in treating waters from contaminated sources is to minimize potential consumer exposure to organics with respect to both the number and concentrations of organic chemicals. It was primarily to this end that granular activated carbon was installed at the EEWTP, as discussed in prior chapters.

During the course of this project, the finished waters from the EEWTP and the local metropolitan Washington WTPs were analyzed for a wide range of specific organic compounds. A total of 151 compounds were routinely sought in the finished water, while over 300 other compounds were tentatively identified in different water samples taken over the two year monitoring period. In addition, two surrogate organic measures, total organic carbon (TOC), and total organic halide (TOX), were monitored. The results of these analyses are presented in this section, with discussion centered on the following groups of parameters.

#### Surrogate Parameters

- Total Organic Carbon
- Total Organic Halide

#### Synthetic Organics

- Trihalomethanes
- Regulated Pesticides and Herbicides
- Volatile Organics Under Consideration for Federal Regulation
- Additional SOC's Targeted for Analysis
- Secondary SOC's Tentatively Quantified

Overall, the level of synthetic organics in EEWTP finished water during all phases of operation was quite low. This is to be expected because of the use of granular activated carbon adsorption. Both surrogate parameters, TOC and TOX, were consistently found at lower levels than at any of the local plants. The geometric mean values for TOC for all three phases were less than 2 mg/L-C, and for TOX were less than 80  $\mu\text{g/L-Cl}$ . The geometric mean values for trihalomethanes measured at the EEWTP ranged from 1 to 8  $\mu\text{g/L}$  for the three phases, again much lower than at the local plants. The regulated pesticides and herbicides were never detected in EEWTP finished water. The six volatile

## Organic Parameters

organic compounds under consideration for federal regulation were detected in less than 15 percent of the samples. In the cases where positives occurred, the values were always less than 5 µg/L, and generally less than 1 µg/L. These levels are not likely to be of health concern to consumers. Additional SOCs, either targeted for analysis or identified during routine sampling were also detected very infrequently, and values remained below 10 µg/L. Specific analysis of the results obtained for each of these groups is given below.

### SURROGATE PARAMETERS

#### TOTAL ORGANIC CARBON

Total organic carbon (TOC) is a general surrogate parameter for organics of natural origin such as chemical and microbial degradation products of vegetation (humus), as well as contaminants introduced by industry. Typically, these latter contaminants comprise a very small fraction of the total mass of TOC; the majority arises from dissolution of naturally-occurring organics. For treatment processes (such as GAC), TOC is often used as a surrogate parameter for organic treatment because its removal may be indicative of the removal of a wide spectrum of organic compounds.

The measurement of TOC includes both dissolved and particulate forms of organic carbon. In this monitoring program, the instrumentation utilized (see Chapter 4) measured both the dissolved and particulate fractions of TOC that could be oxidized to carbon dioxide.

Consideration of this water quality parameter is of recent origin in the water treatment field. Prior to the 1970's, TOC was rarely measured. Since then surveys conducted by EPA have indicated that TOC values can range from approximately 1 mg/L-C in sources obtained from mountainous regions up to 100 mg/L-C in highly colored waters originating in swampy areas such as in the Southeastern portions of the United States. According to one survey conducted in the U. S. (Symons, 1975), the median TOC value in finished water from eighty surface supplies sampled was 1.5 mg/L-C. The median TOC from the surface waters sampled was 3.5 mg/L. This can be compared to TOC levels in secondary effluent which range from 4 to 20 mg/L as C.

Currently there is no standard for TOC in the NIPDWR. It is unlikely that a TOC standard will be proposed because of the lack of specificity of this parameter and the lack of correlation between TOC and health risks. However, TOC may be considered as a potential parameter to be adopted for operational criteria, particularly with respect to regeneration of activated carbon.

Statistics describing the levels of TOC in the three local WTPs monitored and in the finished water from the EEWTP during the three phases of operation are summarized in Table 9.7-1. The geometric mean TOC values of the local plants ranged from 2.3 to 3.8 mg/L-C with 90th percentile values approaching 5 mg/L-C.

## Organic Parameters

TABLE 9.7-1  
COMPARISON OF FINISHED WATERS  
ORGANIC SURROGATE PARAMETERS  
AFFECTING WATER TREATMENT

Parameter	EEWTP			
	Phase IA	Phase IB	Phase IIA	
			WTP 1	WTP 2
				WTP 3
Total Organic Carbon (mg/L-C)	N = 294	N = 41	N = 388	N = 383
Geometric Mean/Spread Factor	1.43/1.65	1.23/1.44	2.27/1.25	2.44/1.25
Arithmetic Mean/Standard Deviation	1.59/0.60	1.30/0.39	2.33/0.57	2.51/0.58
Median/90 Percentile	1.7/2.2	1.38/1.8	2.3/2.9	2.4/3.3
Total Organic Halogen (µg/L-Cl)	N = 299	N = 41	N = 423	N = 405
Geometric Mean/Spread Factor	77.90/2.17	32.28/2.08	262.21/1.38	246.28/1.49
Arithmetic Mean/Standard Deviation	97.62/58.42	39.00/18.93	275.06/79.56	266.73/110.33
Median/90 Percentile	90.0/195.0	40.0/60.0	280.0/365.0	240.0/410.0

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These values are slightly above the median value obtained in the above mentioned survey of U. S. surface water supplies.

Values obtained during all phases of EEWTP operations were generally lower than those at the local plants. Figure 9.7-1 illustrates that TOC values obtained for the EEWTP finished water for all phases were consistently below those at local plants.

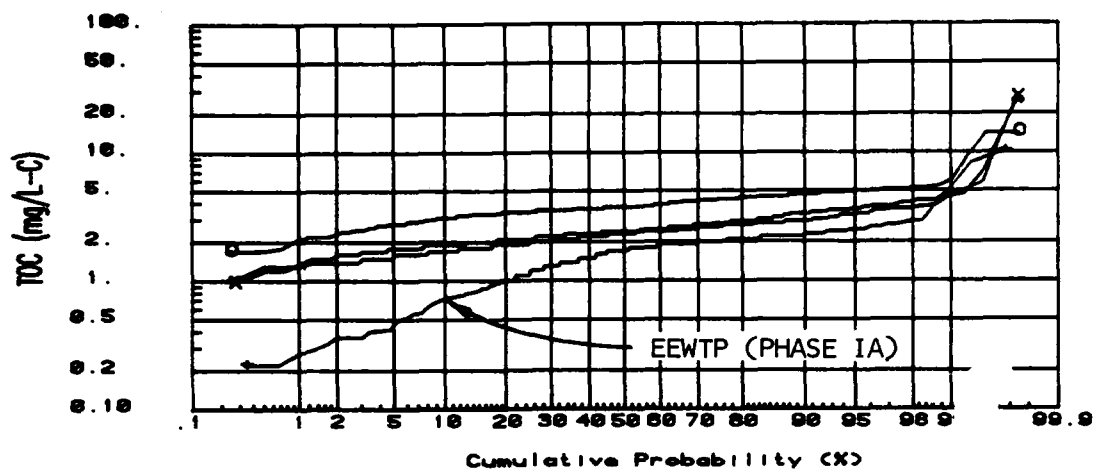
Table 9.7-1 corroborates this observation. The geometric mean values for the EEWTP Phases IA, IB, and IIA finished waters are 1.46, 1.23, and 0.67 mg/L-C respectively, substantially lower than the geometric mean value of 2.29 mg/L-C obtained at the local plant with the lowest value. Similarly, the median and 90th percentile values at the EEWTP are lower than corresponding values at the local plants. The few values above 5 mg/L-C obtained during Phase IA were still below the highest values obtained at the local plants.

The overall lower TOC values observed in the EEWTP effluent are due primarily to use of granular activated carbon (GAC) which significantly reduces the levels of TOC following chemical clarification and filtration. The TOC values in the influent water averaged approximately 5 mg/L-C. This presented no treatment difficulties for reducing TOC to below 2 mg/L-C.

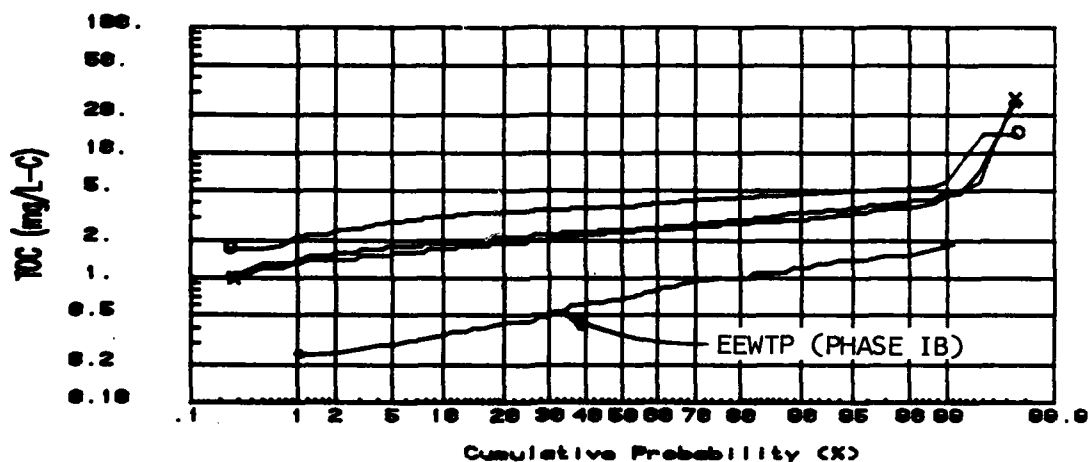
The observed levels of TOC in the EEWTP finished water were related to the operational strategies used to operate the GAC columns. In general, the carbon columns were operated to consistently maintain the TOC below 3 mg/L-C with regeneration frequency as discussed in Chapters 7 and 8. This level was selected in order to minimize the concentrations of trihalomethanes (THM) and total organic halides (TOX) which are formed when free chlorine is utilized as the disinfectant. This was based on a commonly observed relationship between the amount of THM formed and the level of TOC. The formation of THM depends on numerous factors, but in general, it has been observed that for every milligram of dissolved organic carbon, approximately 25-50 µg of THM are formed. Maintaining the TOC at a low level thus has the advantage of reducing the levels of oxidant by-products either from free chlorine or ozone. It further minimizes the potential for regrowth of microorganisms in a distribution system. In practice, carbon regeneration during the alum phase was conducted when the effluent was consistently at or above 2 mg/L TOC, as discussed in Chapter 7.

It is important to note that the GAC effluent never reached the regeneration criteria during Phases IB or IIA. The finished waters from these phases thus represent a partial GAC run and effectively reflects TOC regeneration criteria of approximately 1.8 mg/L and 1.5 mg/L for Phases IB and IIA, respectively.

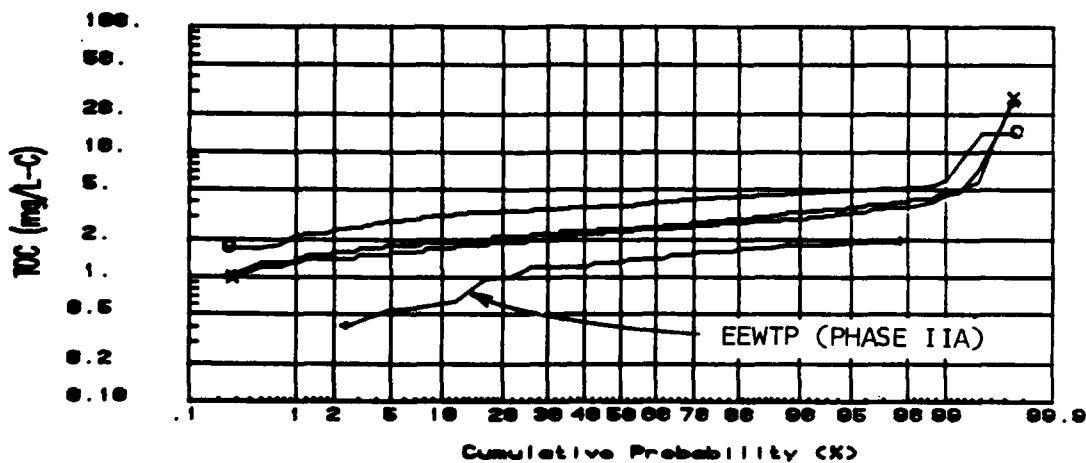




(a) Total Organic Carbon (TOC) in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Total Organic Carbon (TOC) in EEWTP Finished Water (16 March 1982 to 6 July 1983 - Phase IB) and at Three Local WTPs (All Available Data)



(c) Total Organic Carbon (TOC) in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**TOTAL ORGANIC CARBON ( TOC ) IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 7-1**

## Organic Parameters

The TOC levels measured in EEWTP finished water are not at levels of concern, although the appropriate criteria for TOC concentrations in drinking water from contaminated sources is still a subject of some debate. In any event, it should be noted that finished water TOC levels down to about 0.7 mg/L could be achieved with sufficiently frequent carbon regeneration, although costs would become extensive. This issue is discussed further in Chapters 10 and 11.

### TOTAL ORGANIC HALIDE

Total organic halide is a measure of dissolved organic matter containing halide atoms (iodide, chloride, fluoride, bromide). These originate either from reactions between chlorine and organic matter or from halogenated synthetic organic chemicals, discharged to source waters.

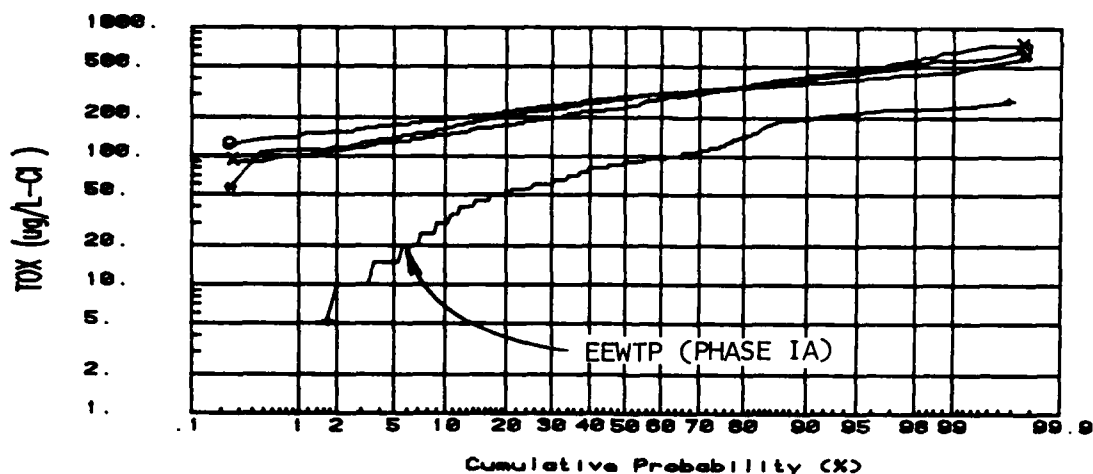
As is discussed in the Methods Section (Chapter 4) the TOX analysis measures those halide-containing compounds that can be adsorbed on granular activated carbon. It is a non-specific measure of both the volatile and the non-volatile organic halide compounds including the trihalomethanes (THM). Generally, it has been found that the TOX level is usually two to twenty times the THM level on a mass basis. The ratio will depend on numerous factors which are discussed in Chapter 10.

There is currently no indication of any relationship between TOX levels and health effects, although research in this area is proceeding. No standard for TOX exists, nor is one being considered at this time in the U.S.. West Germany, however, has a recommended TOX criterion of 25  $\mu\text{g/L-Cl}$ , a recommendation based on concern for controlling chlorinated synthetic organic chemicals found in river water sources.

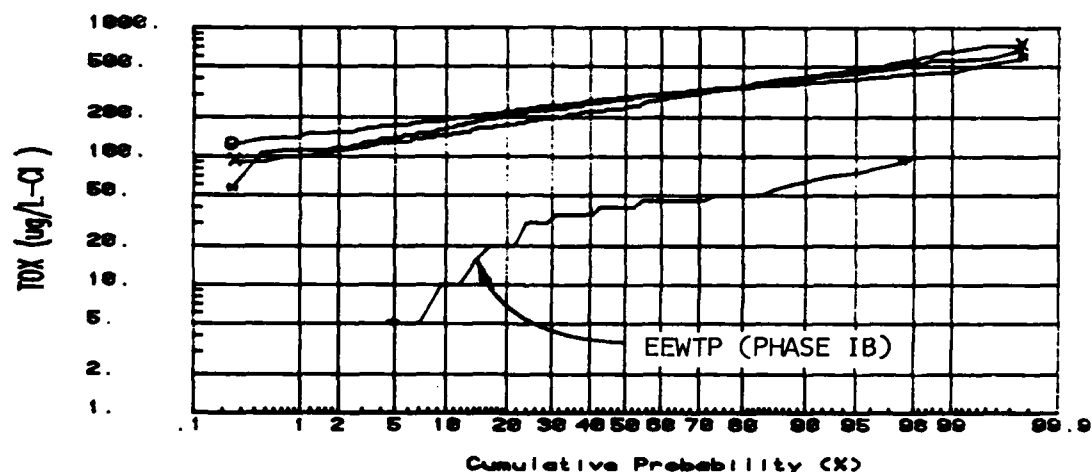
TOX values obtained during operation of the EEWTP showed the same pattern found for TOC; concentrations were lower in the EEWTP finished water during all phases than occurred in the local plants. Table 9.7-1 and Figure 9.7-2 summarize the situation. Geometric mean values for the three local WTPs ranged from 240 - 280  $\mu\text{g/L-Cl}$ , with 90th percentile values up to 400  $\mu\text{g/L-Cl}$ . These levels are typical for finished waters undergoing free chlorination as the final disinfectant and given initial TOC levels of about 3 mg/L-C. The geometric mean values obtained at the EEWTP ranged from 25 - 80  $\mu\text{g/L-Cl}$ , with 90th percentile values up to 200  $\mu\text{g/L-Cl}$ .

The frequency distributions for TOX levels for the three operational periods compared to the three local plants in Figure 9.7-2 graphically illustrate this difference. As shown, TOX levels were always lower than the TOX values observed in the local plants during each of the three operational periods.

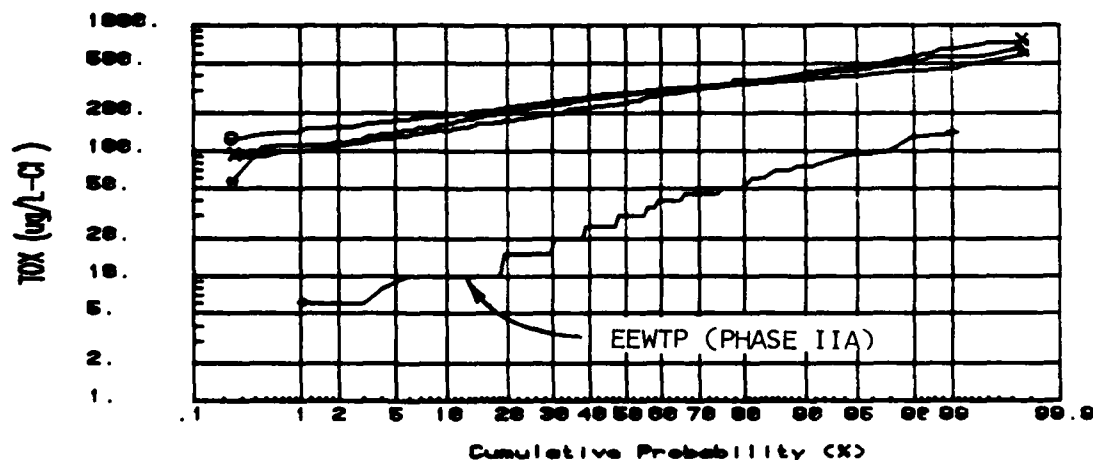
The lower levels observed during Phase IA compared to local WTP finished water values are due to several factors, including lower TOC levels and thus lower levels of precursors for TOX formation, increased removal of influent TOX through GAC treatment, and lower free chlorine residuals. During Phase IB, lower TOX values in the finished water were observed due to the use of ozone as the intermediate oxidant in place of chlorine. Finally, during the third



(a) Total Organic Halides (TOX) in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Total Organic Halides (TOX) in EEWTP Finished Water (16 March 1982 to 6 July 1982 - Phase IB) and at Three Local WTPs (All Available Data)



(c) Total Organic Halides (TOX) in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**TOTAL ORGANIC HALIDES ( TOX ) IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 7-2**

## Organic Parameters

operational period, Phase IIA, ozone plus chloramines replaced free  $\text{Cl}_2$  as the final disinfectant and thus the TOX values observed occur principally because of the TOX levels in the influent water, with small amounts of TOX formed during chloramination, as was discussed in Chapter 8.

It should be noted that the TOX levels monitored were based on samples taken prior to the release to the distribution system. In the presence of free chlorine it can be expected that TOX levels would increase and thus the levels of TOX in the water at the tap would be higher by some factor dependent upon the time in the distribution system, the level of free chlorine residual, and the pH and temperature of the water. Formation tests were conducted as part of the engineering studies for this project, and are discussed in Chapter 10.

Because of the lack of any standard for TOX in the United States, and because no health effect correlations have been developed to date, it is not possible to evaluate the health significance of the TOX levels observed in this monitoring program. TOX levels found in the local plants are typical of water treatment plants in the United States which use free chlorine as an intermediate and/or final disinfectant.

In summary, the TOX levels produced at the EEWTP were lower than those observed in the plants under all conditions monitored. As with TOC, lower levels of TOX than those observed would be achievable with sufficiently frequent carbon regeneration. In this case, the EEWTP results indicate that approximately  $25 \mu\text{g/L-Cl}_2$  is the lowest level of TOX which could be practically achieved.

## SYNTHETIC ORGANIC CHEMICALS

In addition to the two surrogate parameters, TOC and TOX, a large number of individual organic compounds were monitored during this project. These synthetic organic chemicals (SOC) originate from three sources. They may be of human origin discharged into the estuary or into the wastewater treatment plant. They may be of natural origin produced by bacteria and other aquatic organisms, an example being odor-producing compounds such as geosmin. Finally, some compounds originate from reactions between the oxidants added during the treatment process and naturally occurring organic materials.

Since 1974, several hundred synthetic organic chemicals have been identified and quantified in drinking waters in the United States for systems utilizing surface sources. It is estimated, however, that current analytical techniques are capable of identifying only about ten percent of the organic chemicals present in drinking water. Most of these compounds are relatively volatile parameters that can be measured by gas chromatographic techniques. Currently over six million chemicals have been formulated by the chemical industry worldwide and of those, approximately 50,000 are in regular commercial use. A great many of these, in turn, find their way into water supplies. Thus, as analytical techniques improve, the number and variety of compounds detected and quantified in drinking waters are expected to increase.

## Organic Parameters

Although there is potential for widespread trace contamination of drinking water sources by synthetic organic chemicals, reported monitoring data indicate that the levels are generally low, less than 10 µg/L. The major exception is the group of compounds produced by the disinfection process with free chlorine, known as trihalomethanes.

In this particular study, a number of analytical techniques were utilized in an attempt to identify and quantify synthetic organic chemicals. The analytical extraction techniques utilized included liquid/liquid extraction,<sup>1</sup> the purge and trap technique (volatile organics analysis), closed-loop stripping, base-neutral extraction, and acid extraction.<sup>2</sup> The description of the methods and the specific protocols for extraction and subsequent analysis are included in Chapter 4 and Appendix A, respectively. In addition, a limited amount of monitoring was conducted using some of the most recently developed techniques, as discussed in Appendix J. These include steam distillation, ion exchange analysis with both anion and cation exchange resins, high pressure liquid chromatography, modified liquid/liquid extraction for dihaloacetonitriles, and high resolution GC/MS.

The following discussion is a quantitative and descriptive comparison of the levels of SOC observed in the routine monitoring of EEWTP finished waters during the three operational periods and the observed values in the local plants during the entire twenty-three month sampling period. Out of 151 SOC<sub>s</sub> originally targeted for analyses, only the four trihalomethanes and nine additional compounds occurred in either EEWTP finished water or in one or another local plant's finished water with sufficient frequency to calculate a geometric mean. The minimum frequency of positive values (greater than the MDL) for this calculation was 15 percent. Of the over 300 additional compounds tentatively identified during routine monitoring in all sites, 27 were also detected in more than 15 percent of the samples. Only about 100 of these compounds were detected in the finished water sites. This latter group was not originally slated for analysis as standards were not utilized and their quantitation was tentative. Thus, only ranges of tentative concentrations for these compounds are reported.

The six regulated pesticides and herbicides, the six volatile organics being considered for federal regulation, and the remaining targeted and secondary SOC<sub>s</sub> were not detected with sufficient frequency to allow more than semi-quantitative analysis. Thus frequency-of-occurrence data and ranges of observed concentrations for these compounds are reported.

1. For THMs, PCE, TCE, CCl<sub>4</sub> as well as pesticide, herbicide and PCB fractions, see Chapter 4.
2. After 1 December 1981, acid extraction samples were methylated, see Chapter 4.

### TRIHALOMETHANES

The trihalomethanes (THMs) are halogenated SOC's which have been identified as the product of drinking water chlorination and are currently regulated by the EPA. They technically include any compound containing a methyl group ( $\text{CH}_3$ ) with three of the hydrogens replaced by a halide, such as chloride, bromide, fluoride or iodide. However, for the purposes of regulation, the EPA has limited the definition of THMs to include only the following four individual compounds: chloroform, bromodichloromethane, dibromochloromethane and bromoform. These four parameters can be determined by several analytical techniques. Monitoring data for these four compounds by all applicable techniques are summarized in Appendix H. For the purposes of the comparison reported here, only the liquid/liquid extraction data based on composite samples are discussed.

A comparison of the relevant statistics for total trihalomethanes (TTHMs) concentrations in all finished waters is provided in Table 9.7-2. The geometric means observed in the local plants range from 48 to 64  $\mu\text{g/L}$ . For the plant with the highest observed values, the 90th percentile value is 100  $\mu\text{g/L}$ . These values are typical of treatment plants treating a surface water with low levels (<4 mg/L-C) of TOC and using free chlorine disinfection and/or free chlorine addition before filtration.

In contrast, the geometric mean values obtained during the three operational phases were much lower, ranging from 1 to 8  $\mu\text{g/L}$ . The highest 90th percentile value for the three phases was 25  $\mu\text{g/L}$ . The complete frequency distribution of TTHM concentrations for the three operating periods is compared to the local plants in Figure 9.7-3. As was the case for total organic halide, the EEWTP exhibits values of THM that are lower than the local plants in all samples collected.

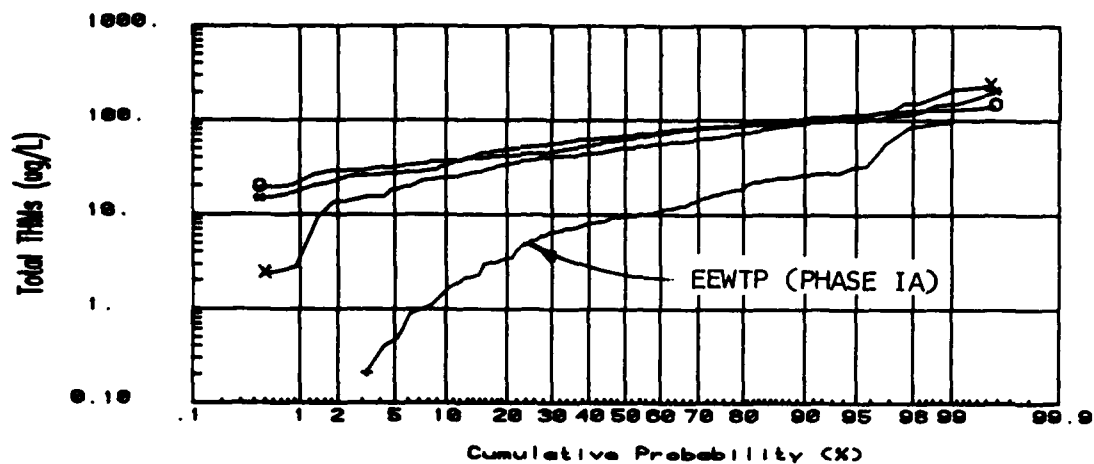
#### Comparison to Standard

The National Interim Primary Drinking Water Regulations (NIPDWR) MCL for total THM is 0.10 mg/L based on a running yearly average of quarterly samples. At least three of the four samples, however, must be taken from the distribution system. In this project, samples at the local plants were taken prior to release to the distribution system in order to be comparable with samples taken from the EEWTP. Thus, a comparison between the EEWTP and the finished water sites was considered the best approach for evaluating finished water quality, rather than comparison to the MCL. Some bench-scale, 4-day and 7-day potential TTHM tests were conducted on EEWTP and local finished waters to mimic potential retention times in a distribution system. The results of these tests showed EEWTP water again compared favorably with the local plants. Bench-scale tests for both 4-day and 7-day formation did not indicate potential TTHMs in EEWTP samples in excess of the MCL, see Chapter 10.

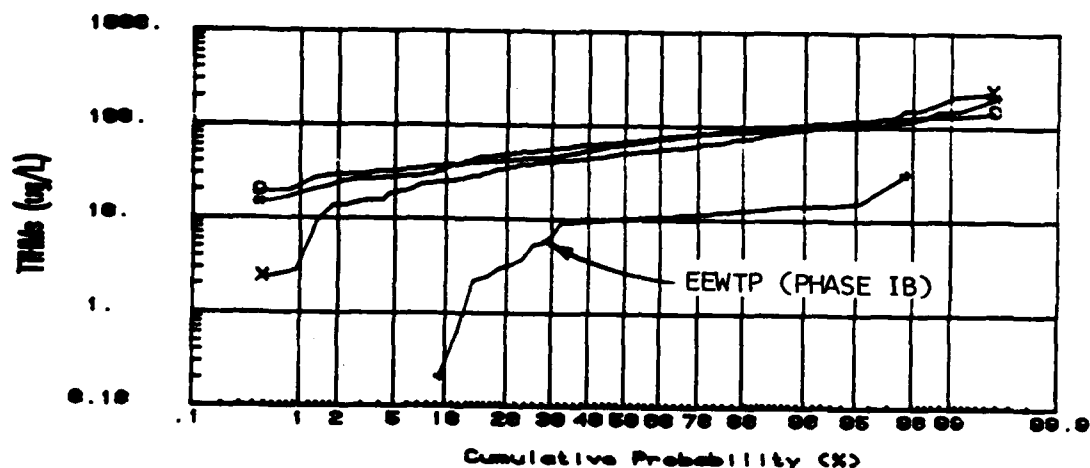
## Organic Parameters

TABLE 9.7-2  
COMPARISON OF FINISHED WATERS  
TOTAL TRIHALOMETHANES BY LIQUID-LIQUID EXTRACTION  
(All concentrations in  $\mu\text{g/L}$ )

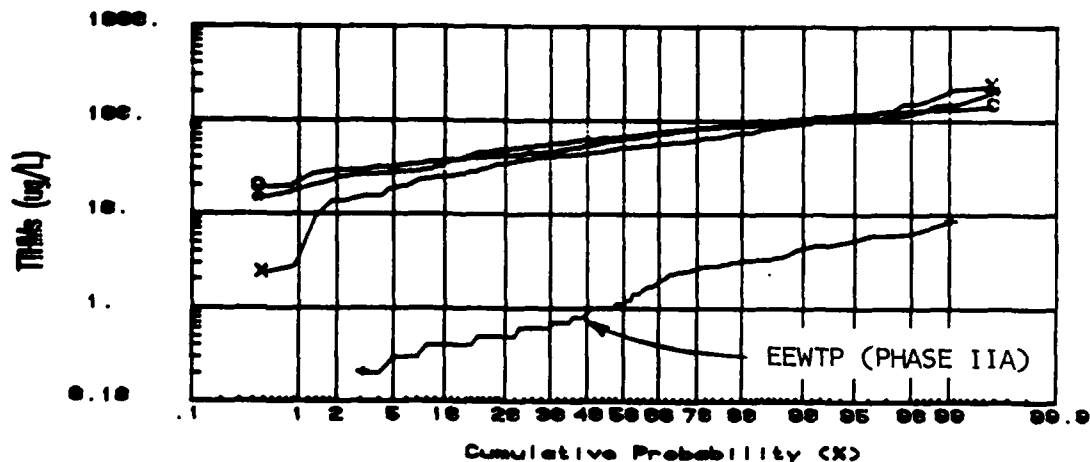
	EEWTP				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
No. Det'd/No.	92/94	39/42	97/99		226/226	228/228	209/209
Geometric Mean	7.72	5.77	1.25		63.59	61.37	48.19
Spread Factor	3.37	3.95	2.58		1.50	1.49	1.79
Arithmetic Mean	13.14	9.16	1.87		68.46	66.35	55.88
Standard Deviation	14.77	5.68	1.65		24.75	25.97	31.45
Median	9.5	10.1	1.1		67.3	63.2	50.8
90%	25.1	14.0	4.3		95.3	102.9	92.6



(a) Total Trihalomethanes (Total THMs) in EEWTP Finished Water (16 March 1981 to 16 March 1982 - Phase IA) and at Three Local WTPs (All Available Data)



(b) Total Trihalomethanes (Total THMs) in EEWTP Finished Water (16 March 1982 to 6 July 1982 - Phase IB) and at Three Local WTPs (All Available Data)



(c) Total Trihalomethanes (Total THMs) in EEWTP Finished Water (16 July 1982 to 1 February 1983 - Phase IIA) and at Three Local WTPs (All Available Data)

**TOTAL TRIHALOMETHANES ( TOTAL THMs ) IN EEWTP FINISHED WATER  
AND AT THREE LOCAL WTPs  
FIGURE 9. 7-3**



## Organic Parameters

### Specific Trihalomethane Compounds

The THM standard in the NIPDWR is based on total trihalomethanes, defined as the arithmetic summation of the mass concentration of the four species. Although chloroform is the only THMs to date that has been shown to be carcinogenic in animals there is some concern that the brominated THMs may pose a greater health risk to consumers than chloroform.

Table 9.7-3 summarizes the relevant statistics for the individual THM species for the three local finished waters compared to the levels observed during the three phases of the EEWTP operation. The geometric means for chloroform and bromodichloromethane in the EEWTP finished water are less than the geometric mean values of the local plants during all phases of operation. These values are significantly less at the 0.05 significance level.

In the case of dibromochloromethane ( $\text{CHClBr}_2$ ), however, the geometric means estimated from concentrations observed during Phases IA and IB are higher than at one of the local plants, WTP2. During Phase IIA, the geometric mean was again lower than all the local plants due primarily to absence of free chlorine as a final disinfectant. For Phases IA and IB, while the level of  $\text{CHClBr}_2$  in the EEWTP finished water is greater than the local plant, the estimated geometric mean values are less than  $5 \mu\text{g/L}$ . Although there are no published risk assessment data available for dibromochloromethane, a  $5 \mu\text{g/L}$  concentration is unlikely to have a risk level greater than EPA's estimated one in a million ( $10^{-6}$ ) incremental cancer risk level for chloroform.

Bromoform is the brominated species of THM which is usually observed in very low levels in finished waters. This is due to the generally low levels of bromide ion found in surface waters. As was expected in the local plants, this compound was rarely detected, and consequently the geometric means were not estimated because the percent positives did not meet the fifteen percent positive criteria.

The values observed in the EEWTP finished water exceeded those values in the local plants because of higher bromide levels in the source water. Ninety percent of the observed values, however, did not exceed  $5 \mu\text{g/L}$  during any phase of operation, and the geometric means were below  $1 \mu\text{g/L}$ . Currently there are no health effects data available for bromoform. According to Drinking Water and Health, (NAS, 1980), there is insufficient data to determine the acceptable levels of bromoform in drinking water. Compared to the MCL for TTHM of  $0.10 \text{ mg/L}$ , the level of risk associated with the bromoform levels observed in the finished waters of the EEWTP is expected to be negligible.

TABLE 9.7-3  
COMPARISON OF FINISHED WATERS  
TRICHALOMETHANES BY LIQUID-LIQUID EXTRACTION

Parameter ( $\mu\text{g/L}$ )	EEWTP			WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA			
Chloroform						
No. Det'd/No.	93/98	34/41	81/99	227/227	230/230	209/209
Geom Mean/SF	4.06/3.27	1.47/3.22	0.77/2.90	50.05/1.56	52.34/1.54	36.62/1.91
Arith Mean/SD	7.30/11.02	2.35/1.95	1.23/1.04	54.68/22.15	57.39/24.83	44.27/29.55
Median/90%	5.0/11.0	2.1/5.2	0.8/2.8	54.0/80.0	52.0/95.0	38.0/77.0
Bromodichloromethane						
No. Det'd/No.	92/99	34/41	34/99	227/227	230/230	208/209
Geom Mean/SF	2.17/3.06	1.56/3.11	0.20/2.59	11.21/1.46	7.45/1.46	8.59/1.71
Arith Mean/SD	3.60/3.50	2.36/1.66	0.35/0.33	11.95/3.99	7.98/3.00	9.55/3.84
Median/90%	2.5/8.7	2.5/3.6	NQ/0.9	12.0/16.0	7.4/12.0	9.4/15.0
Dibromochloromethane						
No. Det'd/No.	91/99	36/41	32/99	227/227	229/230	207/209
Geom Mean/SF	1.35/2.99	2.06/3.55	0.10/3.87	1.69/1.62	0.73/1.80	1.46/1.95
Arith Mean/SD	2.13/1.84	3.30/2.36	0.28/0.40	1.90/1.08	0.88/0.63	1.80/1.36
Median/90	1.6/5.3	3.9/5.5	NQ/0.8	.8/2.8	0.71.7	1.6/3.1
Bromoform						
No. Det'd/No.	50/99	29/41	17/99	13/227	6/230	12/209
Geom Mean/SF	0.22/3.49	0.64/4.06	0.04/5.03	— <sup>a</sup>	—	—
Arith Mean/SD	0.42/0.52	1.20/1.09	0.15/0.26	0.09/0.15	0.06/0.04	0.13/0.45
Median/90%	0.2/1.1	1.1/2.1	ND/0.4	ND/NQ	ND/ND	ND/NQ

a. Geometric mean not calculated if less than 15 percent of samples were quantified.

### PESTICIDES/HERBICIDES

In addition to the trihalomethanes, the National Interim Primary Drinking Water Regulations include MCLs for six additional organic compounds, all of which are pesticides. These include Endrin, gamma-BHC (Lindane), Methoxy-chlor Toxaphene, 2,4-D and 2,4,5-TP Silvex. MCLs for these compounds have been set at 0.2, 4, 100, 5, 100 and 10  $\mu\text{g/L}$ , respectively. These six pesticides were monitored on a tri-weekly basis during the course of the project. The methods and protocols for these compounds are discussed in Chapter 4 and Appendix A, respectively.

Pesticides were detected three times in two of the three local WTPs. In all cases, however, the levels observed were less than the method detection limit (MDL). During all three operational periods of the EEWTP, no pesticides or herbicides were ever detected in the finished water. Statistical summaries of the results for the pesticide and herbicide fraction for the finished waters are summarized in Appendix H.

### VOLATILE ORGANIC CHEMICALS

The Environmental Protection Agency (EPA) is currently in the final stages of promulgating MCLs for selected volatile organic chemicals (VOC) which have been found in increasing frequency in U.S. drinking waters, particularly groundwaters. As discussed in Chapter 1, Section 5, it is anticipated that MCLs will be set for at least five or six of the VOC being considered for regulation, with the expected MCLs ranging from 1 to 1,000  $\mu\text{g/L}$ .

The values observed in this project for the six selected volatile organic chemicals are summarized in Table 9.7-4. The compounds were determined either by liquid/liquid extraction (LLE) or the purge-and-trap (VOA) method. In addition, some of these parameters were quantified with the closed loop stripping analysis. In all cases, the levels detected were less than 5  $\mu\text{g/L}$ . As shown in Table 9.7-4, geometric means were not estimated by LLE or VOA analysis because the number of positives was less than fifteen percent. Generally, the 90 percent values were less than 1  $\mu\text{g/L}$ .

Although not quantifiable by the previously reported analytical technique (purge and trap), CLS results for tetrachloroethene (PCE) do show some quantified values, with higher observed values in EEWTP finished waters. Because PCE is a confirmed animal carcinogen (Crump and Guess, 1980), the marginally higher observed levels in EEWTP finished water merit further discussion.

The current EPA estimates for a one in a million incremental lifetime cancer risk are 3.5  $\mu\text{g/L}$  for PCE in drinking water (NAS, 1977). The average concentrations at all monitored sites, however, were well below 0.02  $\mu\text{g/L}$  with the highest estimated geometric mean equal to 0.053  $\mu\text{g/L}$  in Phase IIA. The majority of all observed finished water PCE concentrations were less than 0.07  $\mu\text{g/L}$ . The highest observed value in any water was 0.23  $\mu\text{g/L}$  in Phase IA, a phase during which six out of nine CLS samples did not have detectable levels

TABLE 9.7-4  
COMPARISON OF FINISHED WATERS  
SELECTED VOLATILE ORGANIC PARAMETERS

Parameter	Units	ESWTP					
		Phase IA	Phase IB	Phase IIA	WTP 1	WTP 2	WTP 3
Carbon Tetrachloride (LLE)	µg/L						
Number Detected/Number <sup>a</sup>		49/99	3/41	0/99	129/227	163/230	100/208
Geometric Mean/Spread Factor		<sup>b</sup>	—	—	—	0.07/3.09	—
Arithmetic Mean/Standard Deviation		<0.2	<0.2	<0.1	<0.2	<0.2	0.12/0.11
Median/90 Percentile		<0.1/<0.2	<0.1/<0.1	<0.1/<0.1	<0.2/0.2	<0.2/0.3	<0.1/<0.2
Trichloroethene (LLE)	µg/L						
Number Detected/Number		12/99	2/41	1/99	41/227	42/230	25/209
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Median/90 Percentile		<0.1/<0.3	<0.1/<0.1	<0.1/<0.1	<0.1/<0.3	<0.1/<0.3	<0.1/<0.3
Trichloroethene (CLS)	µg/L						
Number Detected/Number		50/99	14/41	4/99	83/227	94/230	72/209
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		<0.4	<0.1	<0.4	<0.4	<0.4	<0.4
Median/90 Percentile		<0.4/<0.4	<0.1/<0.4	<0.1/<0.1	<0.1/<0.4	<0.1/<0.4	<0.1/<0.4
Tetrachloroethene (CLS)	µg/L						
Number Det'd/Number		3/9	3/6	9/10	21/32	16/24	16/28
Geometric Mean/Spread Factor		0.0084/11.78	0.0241/5.14	0.0532/3.13	0.0435/3.57	0.0347/2.66	0.0267/2.69
Median/90% Value		<0.1/0.23	<0.01/0.16	0.053/0.17	0.070/0.12	0.047/0.10	0.030/0.077
1,2-Dichloroethane (purge and trap)	µg/L						
Number Detected/Number		0/18	0/8	0/13	0/39	0/40	0/40
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Median/90 Percentile		<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1
Vinyl Chloride (purge and trap)	µg/L						
Number Detected/Number		0/18	0/8	0/13	0/39	0/40	0/40
Geometric Mean/Spread Factor		—	—	—	—	—	—
Arithmetic Mean/Standard Deviation		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Median/90 Percentile		<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1
1,1,1 Trichloroethane (purge and trap)	µg/L						
Number Detected/Number		10/18	0/8	2/13	14/39	6/40	0/40
Geometric Mean/Spread Factor		—	—	—	0.09/2.23	—	—
Arithmetic Mean/Standard Deviation		<0.2	<0.1	<0.2	0.12/0.12	<0.2	<0.2
Median/90 Percentile		<0.2/<0.2	<0.1/<0.1	<0.1/<0.2	<0.1/0.3	<0.1/<0.2	<0.1/<0.2

a. Number Above Instrument Detection Limit

b. Geometric mean not calculated if less than 15 percent of samples were quantified.

## Organic Parameters

of PCE. Thus, the levels of PCE observed in finished waters do not have significant health concern, and the marginally higher estimated means for EEWTP finished water are considered to be of negligible importance.

Specific risk estimates are also available for several of these other volatile organic chemicals. In general, as shown in Table 1.5-7 in Chapter 1, the anticipated concentrations to be assumed as one in a million ( $10^{-6}$ ) incremental cancer risk levels are on the order of  $5 \mu\text{g/L}$ . The values of VOCs found in the EEWTP finished water were thus well below the estimated  $10^{-6}$  incremental cancer risk level for all six compounds.

### ADDITIONAL SYNTHETIC ORGANIC COMPOUNDS TARGETED FOR ANALYSIS

As indicated previously, the original organics monitoring program consisted of quantitative analysis of approximately 151 target compounds, many of which were measurable by more than one of the several analytical techniques. When all techniques were applied to given set of samples, a total of 208 analytical records for specific SOC's was generated.

For most of these compounds, precision and accuracy data were developed and specific standards used. For these targeted compounds, concentrations were quantitated whenever levels were above the method detection limit (MDL).

If over fifteen percent of the samples had quantified values, a geometric mean was estimated using an iterative statistical algorithm as discussed in Chapter 5. Because the technique is statistically rigorous, it allows reasonable estimation of geometric means below the level of quantification (MDL), using calculations based on the positive values and knowledge of the total sample population. Because of the criteria for fifteen percent positive samples, however, only 13 compounds, including the above discussed trihalomethanes, could be so quantified.

Arithmetic means were also estimated for the targeted compounds, using the assumptions discussed in Chapter 5. In this case, if a calculated arithmetic mean was below the MDL, it is reported as "<MDL" in this chapter. Similarly, if the calculated arithmetic mean was below the limit of instrument detection, it is reported as "<IDL".

An additional group of 19 compounds were detected in more than fifteen percent of the samples but had too many values below the MDL for determining a geometric mean. The data for these compounds have been presented in a semi-quantitative way, comparing the frequency of detection and the range of values of the compounds detected. The remainder of the targeted synthetic organic compounds were either never detected or detected infrequently in the finished waters and few observed values were greater than  $1 \mu\text{g/L}$ . Complete summaries of all the data for these compounds are included in Appendix H.

## Organic Parameters

The frequency of detection of the organic chemical compounds by analytical fraction is shown in Figure 9.7-4. As shown, all compounds included in the LLE fraction were detected in both the local finished waters and the finished waters from the EEWTP. In the volatile organic fraction (extracted by purge and trap) approximately 23 out of 56 compounds were detected at least once. The number of compounds detected in the EEWTP finished water during Phase IA was similar to the number observed in the local plants. In Phase IIA the number of compounds in the VOA fraction decreased to eleven, however.

Similar results were observed for those compounds found in the closed-loop stripping fraction. Nineteen compounds were detected at least once in the finished water for the alum phases compared to 22 compounds in one of the local plants. As occurred for the VOA fraction, the number of closed loop stripping compounds was decreased during Phase IIA, with only thirteen compounds detected at least once. None of the monitored compounds in the acid fraction were observed in any of the finished waters.

Two base-neutral compounds were observed in the local plants. In both cases these were phthalates with the concentrations observed less than 1 µg/L.

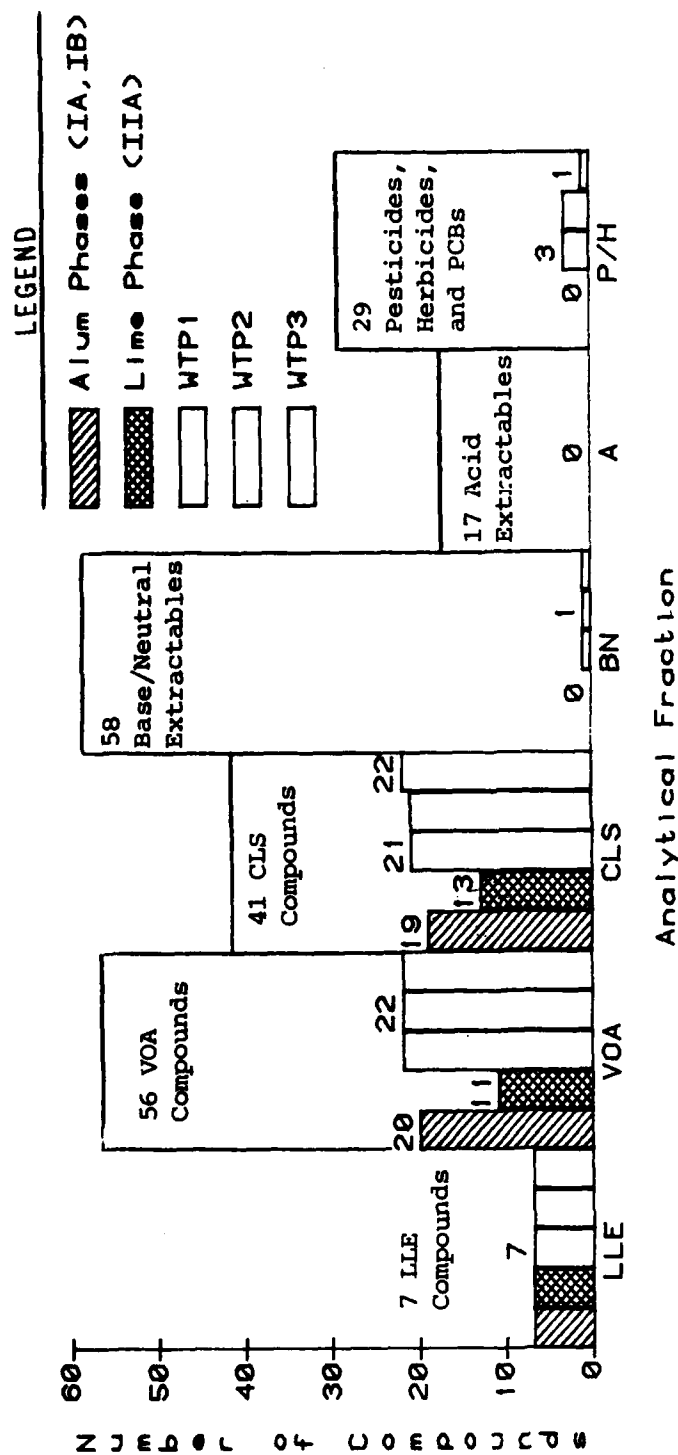
As was discussed previously, three compounds were detected in the pesticide/herbicide fraction in two of the off-site plants. Levels were below the method detection limits, however.

### Compounds Quantified in Fifteen Percent or More of Samples

The specific distributions of concentration for those compounds quantified more than fifteen percent of the time in any one finished water are summarized in Table 9.7-5. As shown, these compounds comprised only a small fraction of the 144 compounds monitored, only fifteen for Phase IA, nine for Phase IB, eight for Phase IIA, and twelve, eight and ten for each of the three local plants. Concentrations were in the range of 0.001 to 10.0 µg/L for the EEWTP finished waters and 0.001 to 100 µg/L for the local plants. The overall higher levels of organic compounds in the local plants were due to their higher levels of trihalomethanes.

Specific quantitative results for the individual compounds for which geometric means were calculated in the EEWTP or the local plants are summarized in Table 9.7-6.

Of the nine compounds shown in Table 9.7-6, only tetrachloroethene (PCE) has been linked to animal carcinogenicity through studies to date. PCE is one of the six VOCs being considered for regulation, and has been previously discussed.



NUMBER OF TARGETED ORGANIC COMPOUNDS  
DETECTED AT LEAST ONCE IN FINISHED WATER

FIGURE 9. 7-4

TABLE 9.7-5  
COMPARISON OF FINISHED WATERS  
NUMBER OF PRIMARY COMPOUNDS QUANTIFIED BASED ON GEOMETRIC MEAN VALUES  
DISTRIBUTION BY CONCENTRATION RANGES

Concentration Range ( $\mu\text{g/L}$ )	EEWTP				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
0.001-0.1	8	4	4		9	5	7
0.1-1.0	3	2	4		0	1	0
1.0-10.0	4	3	0		1	1	2
10-100	0	0	0		2	1	1
>100	0	0	0		0	0	0
	15	9	8		12	8	10



## Organic Parameters

TABLE 9.7-6  
COMPARISON OF FINISHED WATER QUALITY  
SUMMARY OF TARGETED COMPOUNDS QUANTIFIED IN FINISHED WATER<sup>a</sup>

Parameter	Units	EEWTP					WTP 1	WTP 2	WTP 3
		Phase IA	Phase IB	Phase IIA	Phase IIB	Phase IIC			
Dichlorodimethane by LLE Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	3/92 — <0.1/<0.1	—	—	—	—	3/6 — <0.1/<0.1	27/72 0.39/2.06 <0.1/<0.1	6/66 — <0.1/<0.1
Ethylbenzene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	6/9 0.0137/2.88 <0.02/0.063	4/6 0.0185/1.23 <0.02/0.025	4/10 0.0023/12.48 <0.005/0.021	—	—	26/32 0.0183/2.62 <0.02/0.046	18/24 0.0081/4.16 <0.02/0.060	24/28 0.0149/3.11 <0.02/0.055
Toluene by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	3/18 0.01/13.08 <0.1/0.6	0/8 — <0.1/<0.1	0/13 — 0.1/<0.1	—	—	11/39 0.03/8.71 <0.1/0.7	12/40 0.05/4.37 <0.1/0.3	8/40 0.02/9.48 <0.1/0.4
Toluene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	4/9 0.083/2.05 <0.02/0.24	3/6 0.0791/1.37 <0.02/0.13	1/10 — <0.02/<0.02	—	—	17/32 0.076/2.48 <0.02/0.22	11/24 0.071/2.19 <0.02/0.20	14/28 0.053/2.25 <0.02/0.137
1-2 Xylene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	5/9 0.028/2.52 <0.03/0.12	6/6 0.029/SF <0.03/0.033	3/10 — <0.005/<0.03	—	—	22/32 0.02/1.97 <0.03/0.036	12/24 — <0.005/<0.03	17/28 0.023/1.52 <0.03/0.039
1-3-Xylene, 1-4 Xylene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	5/9 0.037/2.74 <0.04/0.19	6/6 0.037/1.17 <0.04/0.048	3/10 — <0.005/<0.04	—	—	21/32 0.018/2.41 <0.04/0.044	9/24 — <0.005/<0.04	17/28 0.014/4.52 <0.04/0.066
Naphthalene by CLS Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	2/9 0.0129/4.81 <0.01/0.158	1/6 — <0.04/<0.04	1/10 — <0.04/<0.04	—	—	6/32 — <0.04/0.135	4/24 — <0.04/0.11	4/28 — <0.04/0.084
Tetrahydrofuran by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	3/10 0.02/9.73 <0.1/0.3	0/8 — <0.1/<0.1	1/13 — <0.1/<0.1	—	—	22/39 0.73/32.17 5.8/22.0	5/40 — <0.1/<0.1	3/40 — <0.1/<0.1
Acetone by VOA Number Det'd/Number Geometric Mean/Spread Factor Median/90% Value	µg/L	2/18 — <0.5/9.6	2/8 0.17/4.72 <0.5/2.8	3/12 0.08/17.90 <0.5/3.4	—	—	11/38 0.12/16.65 <0.5/6.0	7/39 0.02/44.33 <0.5/4.0	7/40 0.03/19.75 <0.5/1.9

a. Compounds targeted for analysis which have been quantified (>MDL) in over 15 percent of the samples from finished water sites; summary of analyses other than those previously reported in Tables 9.7-3 and 9.7-4.

b. Geometric Mean not calculated if less than 15 percent of samples were quantified.

## Organic Parameters

The other results shown in Table 9.7-6 also show no cause for concern based on available information. All mean concentrations were well below 1 µg/L with median values not detected or not quantified in almost all cases.

The distribution by value for all quantified SOC results are summarized in Figure 9.7-5. This figure includes quantifications for the THMs, the quantified VOCs shown in Table 9.7-4, the compounds in Table 9.7-6, and all other compounds for which there were sample concentrations found above the quantification limits (MDL).

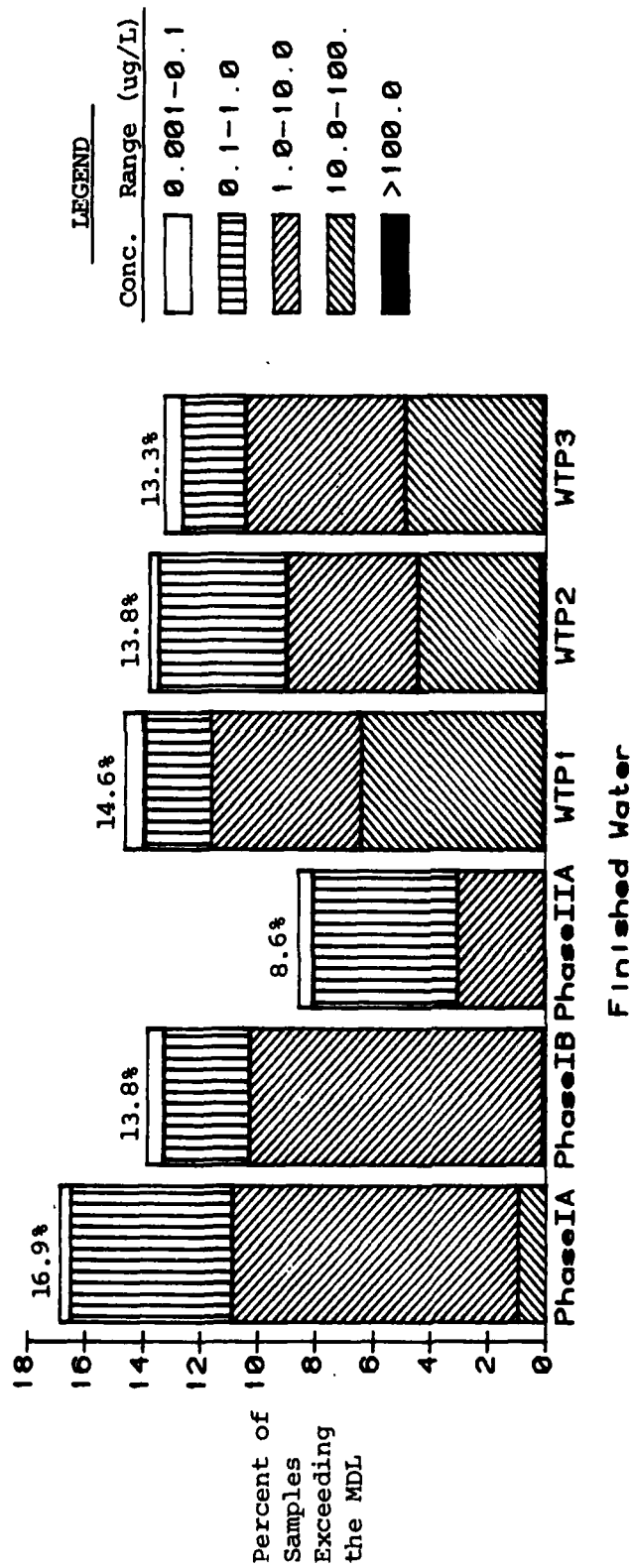
As shown, the percent positives, i.e., those results greater than the MDL, ranged between 13 to 14 percent in the local plants. In comparison, during Phase IA the number of positives reached approximately 17 percent in the EEWTP finished water, largely because of additional positive results for brominated THM species. Use of the ozone/chloramine disinfectant and the more conservative GAC operation in Phase IIA reduced the number of positives to 8.6 percent. The distribution of positive results by concentration category is also shown in Figure 9.7-5. As can be seen, the bulk of the positive values for the EEWTP are in the concentration range of 0.1 to 10 µg/L. In comparison, positive values for the local plants are predominantly in the range of 1 to 100 µg/L. This different distribution is due entirely to the higher levels of trihalomethanes observed in the local WTPs.

The overall summary of the primary organic compounds quantified in the finished waters is shown in Figures 9.7-6 and 9.7-7. Shown in these comparisons are the estimated geometric means from the EEWTP finished water compared to the estimated geometric means for organic compounds quantified in the local plants, with only the highest value from the three plants shown. As can be seen, during Phase IA, the geometric means of highest quantified values in a local plant are higher than the geometric means observed in the finished water from the EEWTP, with the exception of 1,2-xylene. Again, all compounds other than the trihalomethanes had estimated geometric mean concentrations of less than 0.1 µg/L.

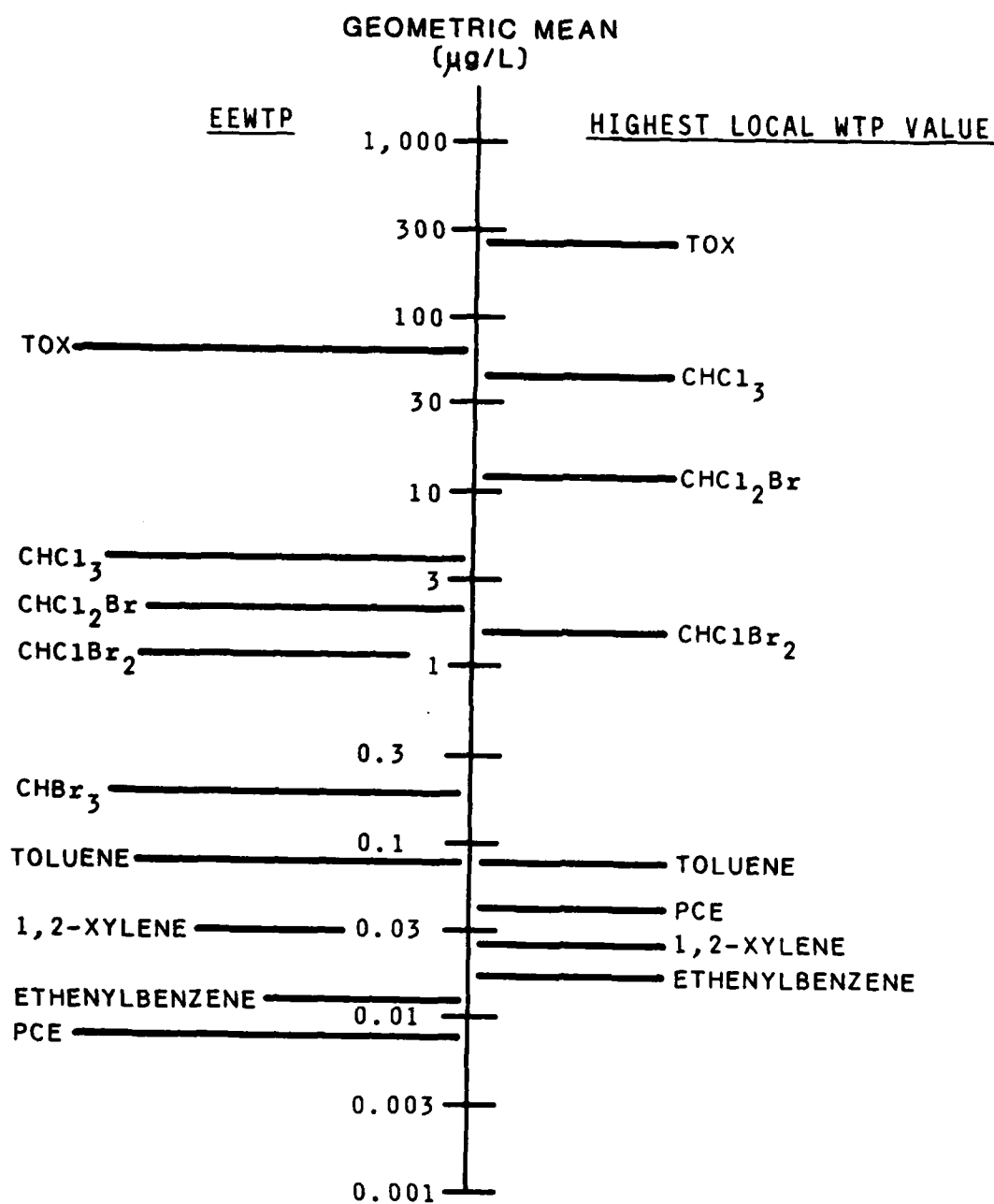
In Phase IIA, utilizing lime as the coagulant, increased GAC empty bed contact time (EBCT), and ozone/chloramine as the disinfectant, the levels of these trace organic compounds decreased substantially. The trihalomethane levels are considerably lower than the local plants. During the Phase IIA operational period, the estimated geometric mean for PCE in the EEWTP finished water was higher than the highest estimated mean at a local plant, as previously discussed.

### Additional Targeted Compounds Detected in Fifteen Percent or More of Samples

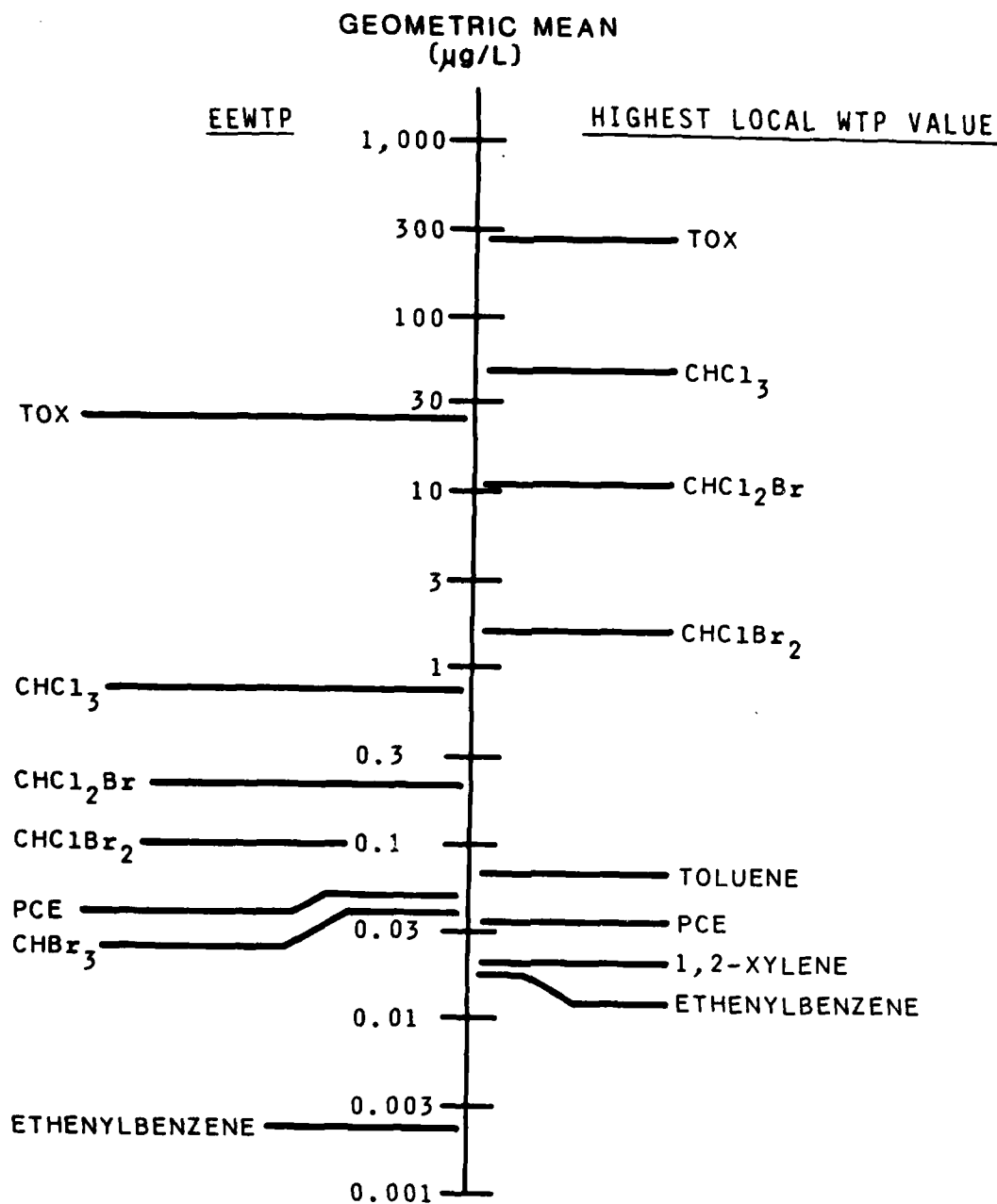
Data for the 19 target organics which were detected in more than fifteen percent of the samples but for which an insufficient number of detections were above the MDL are summarized in Table 9.7-7. The specific number of times each compound was detected and the concentration range within which each



DISTRIBUTION OF QUANTIFICATIONS FOR  
ORGANIC COMPOUNDS IN FINISHED WATERS  
FIGURE 9. 7-5



**COMPARISON OF QUANTIFIED ORGANICS  
IN FINISHED WATERS  
(PHASE 1A)  
FIGURE 9. 7-6**



**COMPARISON OF QUANTIFIED ORGANICS  
IN FINISHED WATERS  
(PHASE IIA)  
FIGURE 9. 7-7**

## Organic Parameters

TABLE 9.7-7

COMPARISON OF FINISHED WATERS  
SUMMARY OF ADDITIONAL TARGETED COMPOUNDS DETECTED IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
Methylene Chloride by VOA Number Det'd/Number Range	1/18 ND-<2.0	0/8 ND	2/13 ND-<2.0		2/39 ND-<2.0	5/40 ND-<3.2	4/40 ND-<2.0
Trichlorofluoromethane by VOA Number Det'd/Number Range	8/18 ND-1.6	1/8 ND-0.5	1/13 ND-3.2		10/39 ND-4.1	11/40 ND-3.6	11/40 ND-13.0
1,1-Dichloroethane by VOA Number Det'd/Number Range	0/18 ND	0/8 ND	2/13 ND-<0.6		0/39 ND	0/40 ND	1/40 ND-<0.6
1,1 2,2-Tetrachloroethane by CLS Number Det'd/Number Range	1/9 ND-<0.05	2/6 ND-<0.05	0/10 ND		2/32 ND-<0.05	1/24 ND-0.066	3/28 ND-0.18
1,2-Dichloropropane by CLS Number Det'd/Number Range	3/9 ND-<0.08	0/6 ND	0/10 ND		1/32 ND-<0.08	2/24 ND-<0.08	2/28 ND-<0.08
Ethylbenzene by VOA Number Det'd/Number Range	5/18 ND-<0.0.1	0/8 ND	0/13 ND		4/39 ND-0.	4/40 ND-0.1	4/40 ND-0.1
Ethylbenzene by CLS Number Det'd/Number Range	7/9 ND-0.13	6/6 ND-<0.04	3/10 ND-0.068		21/32 ND-0.19	11/24 ND-0.09	17/28 ND-0.087

TABLE 9.7-7 (Continued)

COMPARISON OF FINISHED WATERS  
SUMMARY OF ADDITIONAL TARGETED COMPOUNDS DETECTED IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water					
	Alum		Alum		Lime	
	Phase IA	Phase IB	Phase IB	Phase IIA	WTP1	WTP2
Propylbenzene by CLS Number Det'd/Number Range	4/9 ND-0.052	0/6 ND	2/10 ND-0.01	14/32 ND-0.14	8/24 ND-<0.01	8/28 ND-<0.01
	6/18 ND-0.1	0/8 ND	0/13 ND	4/39 ND-0.1	5/40 ND-0.1	5/40 ND-0.1
1,2-Xylene by VOA Number Det'd/Number Range	6/18 ND-<0.4	0/8 ND	0/13 ND	6/39 ND-<0.4	7/40 ND-<0.4	7/40 ND-0.4
	0/3 ND	0/4 ND	0/6 ND	1/12 ND-<8.0	4/14 ND-<8.0	2/12 ND-<8.0
Phenol by Acid with Methylation Number Det'd/Number Range	2/9 ND-<0.02	0/6 ND	0/10 ND	0/32 ND	0/24 ND	0/28 ND
	0/9 ND	1/6 ND-<0.02	0/10 ND	1/32 ND-<0.02	0/24 ND	1/28 ND-<0.02
1,2-Dichlorobenzene by CLS Number Det'd/Number Range	4/9 ND-<0.02	1/6 ND-<0.02	2/10 ND-<0.02	9/32 ND-0.03	2/24 ND-<0.02	6/28 ND-<0.02
	4/9 ND-<0.02	1/6 ND-<0.02	1/10 ND-<0.02	10/32 ND-0.027	6/24 ND-<0.02	7/28 ND-<0.02
1,3-Dichlorobenzene by CLS Number Det'd/Number Range	4/9 ND-<0.02	1/6 ND-<0.02	1/10 ND-<0.02	10/32 ND-0.027	6/24 ND-<0.02	7/28 ND-<0.02
	4/9 ND-<0.02	1/6 ND-<0.02	1/10 ND-<0.02	10/32 ND-0.027	6/24 ND-<0.02	7/28 ND-<0.02

## Organic Parameters

TABLE 9.7-7 (Continued)

COMPARISON OF FINISHED WATERS  
SUMMARY OF ADDITIONAL TARGETED COMPOUNDS DETECTED IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
1,2,3-Trichlorobenzene by CLS Number Det'd/Number Range	2/9 ND-<0.03	0/6 ND	0/10 ND		4/32 ND-<0.03	2/24 ND-<0.03	2/28 ND-<0.03
1,2,4-Trichlorobenzene by CLS Number Det'd/Number Range	4/9 ND-<0.02	0/6 ND	0/10 ND		5/32 ND-<0.02	3/24 ND-<0.02	3/28 ND-<0.02
2-Butanone by VOA Number Det'd/Number Range	0/18 ND	0/8 ND	1/13 ND-1.8		7/39 ND-6.0	2/40 ND-<1.0	3/40 ND-7.1
Geosmin by CLS Number Det'd/Number Range	2/9 ND-<0.05	0/6 ND	2/10 ND-<0.05		10/32 ND-<0.05	6/24 ND-<0.05	12/28 ND-<0.05

1. Compounds targeted for analysis which have been detected in 15 percent of or more of samples. These are in addition to those already reported in Tables 9.7-3 (THMs), 9.7-4 (VOCs) and 9.7-6 (compounds quantified in 15 percent or more of samples).



## Organic Parameters

was detected are shown. The greatest percentage of positives was found in EEWTP Phase IA finished water; out of 183 samples, 59 positives were obtained, or 32 percent. This compares to 12 percent positives in Phase IB finished water, 6 percent positive in Phase IIA finished water, and 22, 14, and 16 percent positives in the finished waters from the three local plants. Ranges of values at all sites ranged from ND to 13.0  $\mu\text{g/L}$  with the highest values obtained at the local plants. As has been mentioned before, the overall lower levels of organics in EEWTP finished water reflects the use of GAC in the treatment process.

### SECONDARY COMPOUNDS

In addition to the 151 primary organic compounds monitored, a substantial number of trace organic compounds were detected during the monitoring period for which no standard had been used in the GC/MS. In those cases the analyst was able to tentatively identify the compound based on a library search of the mass spectra. An approximate concentration was estimated based on the height of the chromatogram relative to standards for compounds of similar molecular structure. Approximately 300 additional organic compounds were tentatively reported using this approach, with nearly 100 tentatively identified in EEWTP and/or local WTP finished water samples. The data are summarized for all finished waters in Tables H-16 to H-19 of Appendix H.

The number of secondary organic compounds detected at least once in all the finished waters from each of the organic fractions monitored is summarized in Table 9.7-8. As seen, the number of secondary compounds detected at least once in the local plants was generally higher than the number of compounds found in the finished waters from the EEWTP. This is most apparent in the closed-loop stripping fraction. Up to 80 compounds were detected at least once in one or more local plants compared to 36 for the finished water from the EEWTP during Phases IA and IB. Again, operation of the EEWTP in Phase IIA substantially reduced the number of secondary compounds found in the individual fractions.

TABLE 9.7-8  
COMPARISON OF FINISHED WATER QUALITY  
NUMBER OF SECONDARY ORGANIC COMPOUNDS  
DETECTED AT LEAST ONCE

Organic Fraction	EEWTP Finished Water		WTP1	WTP2	WTP3
	Phase IA and IB	Phase IIA			
VOA	20	2	29	27	27
CLS	36	13	62	50	80
BN	1	0	2	1	3
Acids	5	3	5	4	4
Pesticides/Herbicides/PCBs	0	0	0	0	0

## Organic Parameters

A more detailed description of the secondary compounds that were detected and quantified in more than fifteen percent of the samples in the finished waters is summarized in Table 9.7-9. Compounds have been listed by fraction and include the number of times in which the compound was tentatively identified in a sample compared to the total number of samples taken. Also shown are the range of tentative concentrations. It is very important to recognize that the identifications of these compounds have not been confirmed and that the estimated concentrations are not accurate. These tentative quantifications are provided solely to provide context with respect to the observed peak heights for these compounds.

In the VOA fraction, five compounds were detected and quantified in more than fifteen percent of the samples from at least one of the four sites. As can be seen, the frequency of occurrence for three of the five compounds was greater in the local plants than at the EEWTP. Two compounds are shown to be more frequently observed in the EEWTP finished water during Phase IA, however. The levels of these compounds were estimated at less than 1  $\mu\text{g/L}$ . All compounds tentatively detected in EEWTP finished water were also found in local MWA finished waters, with only one exception (2,2-oxybispropane). There are no health effects data available on these organic compounds, and it is not possible to assess the health significance at these low levels. However, it is presumed that the presence of these compounds in the sub- $\mu\text{g/L}$  range constitutes a negligible health risk to the consumer.

Three secondary compounds have been tentatively identified in the acid extraction fraction with methylation. In this case, the frequency and levels of these compounds detected in the local WTP finished waters is comparable to those observed in the finished water from Phase IA. Fewer positives are observed in the EEWTP finished water, however. As was the case in the VOA fraction, the Phase IIA operational period showed a decrease in the frequency of occurrence for all compounds.

Most of the secondary compounds observed were measured in the closed-loop stripping fraction, as summarized in Table 9.7-10. Twenty compounds were detected in at least one of the sites in more than fifteen percent of the samples. In general, the frequency of detection and the levels observed in the local plants exceeded those observed in the finished water of the EEWTP during any of the phases of operation. The detection limits for compounds analyzed by the closed-loop stripping reached into the sub- $\mu\text{g/L}$  range, and it is not surprising that low levels of these compounds should be detected in water treatment plants where no treatment barrier exists for the removal of such contaminants. In the case of the EEWTP, however, the use of granular activated carbon has reduced the potential levels of these compounds. As can be seen, operation of the plant during Phase IIA again substantially decreased the frequency and number of positives observed for the closed-loop stripping fraction.

For the local plants, although larger numbers of positives were observed, the estimated concentrations of detected samples were quite low, generally less than 1  $\mu\text{g/L}$ .

TABLE 9.7-9  
COMPARISON OF FINISHED WATER QUALITY  
SUMMARY OF SECONDARY COMPOUNDS FOUND IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
VOAs							
Cyanide Chloride No. Detected/No. Sampled Range	5/18 ND-NQ <sup>2</sup>	0/8 ND	0/13 ND	5/41 ND-NQ	7/41 ND-3.3	4/41 ND-NQ	
2-Methylpropanol No. Detected/No. Sampled Range	2/18 ND-NQ	0/8 ND	0/13 ND	9/41 ND-NQ	9/41 ND-1.9	10/41 ND-0.2	
Pentanal No. Detected/No. Sampled Range	5/18 ND-NQ	0/8 ND	0/13 ND	8/41 ND-NQ	7/41 ND-NQ	8/41 ND-0.3	
1,1-Oxybisethane No. Detected/No. Sampled Range	11/18 ND-0.7	1/8 ND-NQ	1/13 ND-0.1	1/41 ND-14	0/41 ND	0/41 ND	
2,2-Oxybispropane No. Detected/No. Sampled Range	5/18 ND-1.1	0/8 ND	0/13 ND	0/41 ND	0/41 ND	0/41 ND	
Acid Extraction (w/Methylation)							
Dodecanoic Acid No. Detected/No. Sampled	2/5 ND-6	0/3 ND	1/7 ND-5	4/15 ND-6.0	1/16 ND-1	3/15 ND-10	

TABLE 9.7-9 (Continued)

COMPARISON OF FINISHED WATER QUALITY  
SUMMARY OF SECONDARY COMPOUNDS FOUND IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
Hexadecanoic Acid No. Detected/No. Sampled Range	3/5 ND-5	0/3 ND	0/7 ND		3/15 ND-4	2/16 ND-2	4/15 ND-6
Octadecanoic Acid No. Detected/No. Sampled Range	2/5 ND-4	0/3 ND	0/7 ND		1/5 2	0.16 ND	3/15 ND-1
CLSA							
1-Ethyl-2-Methylbenzene No. Detected/No. Sampled Range	7/9 ND-0.03	3/6 ND-0.02	1/10 ND-0.009		17/32 ND-0.07	8/24 ND-0.03	14/28 ND-0.05
1-Ethyl-4-Methylbenzene No. Detected/No. Sampled Range	3/9 ND-0.01	1/6 ND-0.02	1/10 ND-0.007		10/32 ND-0.1	4/24 ND-0.02	6/28 ND-0.03
1,2,3,5-Tetramethylbenzene No. Detected/No. Sampled Range	0/9 ND	0/6 ND	0/10 ND		4/32 ND-0.01	1/24 ND-0.005	4/28 ND-0.01
1,2,4,5-Tetramethylbenzene No. Detected/No. Sampled Range	1/9 ND-0.008	0/6 ND	0/10 ND		4/32 ND-0.01	1/24 ND-0.005	5/28 ND-0.01
1,2,3-Trimethylbenzene No. Detected/No. Sampled Range	6/9 ND-0.07	3/6 ND-0.02	0/10 ND		16/32 ND-0.09	9/24 ND-0.03	14/28 ND-0.06
1,2,4-Trimethylbenzene No. Detected/No. Sampled Range	4/9 ND-0.02	0/6 ND	1/10 ND-0.008		14/32 ND-0.03	8/24 ND-0.03	12/28 ND-0.03

TABLE 9.7-9 (Continued)

COMPARISON OF FINISHED WATER QUALITY  
SUMMARY OF SECONDARY COMPOUNDS FOUND IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water			WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA			
1,3,5-Trimethylbenzene No. Detected/No. Sampled Range	3/9 ND-0.01	0/6 ND	0/10 ND	10/32 ND-0.02	5/24 ND-0.02	4/28 ND-0.02
Decahydronaphthalene No. Detected/No. Sampled Range	0/9 ND	0/6 ND	0/10 ND	0/32 ND	0/24 ND	4/28 ND-0.25
Decahydro-2-Methylnaphthalene No. Detected/No. Sampled Range	0/9 ND	0/6 ND	0/10 ND	0/32 ND	0/24 ND	4/28 ND-0.14
Indau No. Detected/No. Sampled Range	2/9 ND-0.03	0/6 ND	0/10 ND	7/32 ND-0.25	4/24 ND-0.023	4/28 ND-0.028
4-Methylindan No. Detected/No. Sampled Range	0/9 ND	0/6 ND	0/10 ND	3/32 ND-0.02	1/24 ND-0.004	4/28 ND-0.013
1, 1, 1-Trichlorethane No. Detected/No. Sampled Range	5/9 ND-2.2	0/6 ND	0/10 ND	5/32 ND-0.85	3/24 ND-2.9	3/28 ND-0.25
1-Methyl-4-(1-Methylethyl)-7-oxabicyclo-(2, 2, 1) heptane No. Detected/No. Sampled Range	3/9 ND-0.25	0/6 ND	0/10 ND	3/32 ND-0.026	0/24	4/28 ND-0.013
Decanal No. Detected/No. Sampled Range	3/9 ND-0.07	1/6 ND-0.008	2/10 ND-0.09	8/32 ND-0.19	9/24 ND-0.73	7/28 ND-0.05

Organic Parameters

TABLE 9.7-9 (Continued)

COMPARISON OF FINISHED WATER QUALITY  
SUMMARY OF SECONDARY COMPOUNDS FOUND IN  
MORE THAN 15 PERCENT OF SAMPLES IN FINISHED WATERS<sup>1</sup>

Compound	EEWTP Finished Water				WTP1	WTP2	WTP3
	Alum Phase IA	Alum Phase IB	Lime Phase IIA				
Nonanal No. Detected/No. Sampled Range	2/9 ND-0.07	0/6 ND	2/10 ND-0.09	10/32 ND-0.18	12/24 ND-0.50	8/28 ND-0.052	
Heptanal No. Detected/No. Sampled Range	0/9 ND	0/6 ND	4/10 ND-0.1	6/32 ND-0.015	4/24 ND-0.01	3/28 ND-0.022	
Hexanal No. Detected/No. Sampled Range	1/9 ND-0.04	0/6 ND	0/10 ND	6/32 ND-0.04	7/24 ND-0.04	2/28 ND-0.13	
2-Mitropropane No. Detected/No. Sampled Range	0/9 ND	0/6 ND	0/10 ND	5/32 ND-0.14	3/24 ND-0.07	3/28 ND-0.15	
2-Methyl-propanoic acid, butyl ester No. Detected/No. Sampled Range	0/9 ND	0/6 ND	2/10 ND-0.06	2/32 ND-0.3	2/24 ND-0.04	4/28 ND-0.05	

1. Tentative identifications based on comparisons with library mass spectra only; concentration based on height of chromatogram relative to standards for compounds of similar structure; values are therefore approximate, at best.

2. ND = not detected, NQ = not quantified

## Organic Parameters

### SUMMARY

The observed levels of organic parameters in the EEWTP finished waters generally compared quite favorably to the levels observed in the local MWA water treatment plants, both for organic surrogate parameters and individual SOC's. This was especially the case for the finished water resulting from Phase IIA operation, primarily because of 1) operation and chloramination in lieu of chlorination for final disinfection and 2) longer GAC contact time, such that the previously set GAC regeneration criteria were never exceeded during Phase IIA. The fact that GAC was not equally exhausted during Phase IIA can be interpreted as representative of the plant GAC process at an effectively lower regeneration criterion, with resulting improvement in finished water quality for TOC and TOX as well as individual organic compounds. Because the organics were not subjected to free chlorine during final disinfection, concentrations of halogenated species were considerably reduced during Phase IIA, beyond that reflected by TOC reduction.

### SURROGATE PARAMETERS

Levels of TOC and TOX in EEWTP finished waters were significantly lower in waters from local WTPs during all phases of operation. The EEWTP finished waters compared quite favorably to the local plants with respect to these parameters; of themselves, the observed TOC and TOX concentrations indicate no cause for concern with respect to EEWTP finished water quality. For EEWTP operation, these parameters serve primarily as surrogates which reflect upon GAC performance, as discussed in Chapters 7 and 8 and elaborated in Chapter 10. In this context, it is useful to note that the geometric mean TOC concentrations during Phases IA, IB and IIA were about 1.5, 1.2 and 0.7 mg/L-C, respectively. Geometric mean TOX concentrations during these same phases were approximately 78, 32 and 28 µg/L-Cl, respectively.

### INDIVIDUAL TRACE ORGANICS

Of the 151 SOC's targeted for monitoring, only 13 compounds were present at levels sufficiently high to permit 15 percent or more of the samples from any one finished water to be quantified. Of these, only the four trihalomethanes and tetrachloroethene (PCE) have been associated with health effects to date. The EEWTP finished waters (all phases) compared unfavorably to local MWA finished water for dibromochloromethane, bromoform, and PCE. In these latter cases, the concentrations found were rarely above 5 µg/L, however, with geometric means for the latter two below 1 µg/L during all three phases. Health effects at these low levels are not of significant concern based on available information.

For compounds for which the EPA or NAS have estimated one in a million incremental lifetime cancer risks, the EEWTP finished water was always well below the estimated levels. In no case did any sample of EEWTP finished water exceed an EPA MCL for TTHMs or pesticides. Although TTHM samples should rightfully be taken at the end of the distribution system, the EEWTP levels compared quite favorably to local plants, both for instantaneous THMs and THM

## Organic Parameters

formation potential, as demonstrated in bench-scale study (Chapter 10). Six VOCs currently being considered for regulation were generally not detected in at least half of the samples analyzed and were never found at levels of concern.

With respect to all other compounds found in finished waters, none were consistently found at levels for which there currently are suspected health concerns. No compound other than the THMs had a median value in EEWTP finished water above 1 µg/L. This includes consideration of those compounds which could be tentatively identified from library mass spectra. As discussed in Chapter 1, however, it is important to note that many organic compounds can not yet be isolated and/or identified using current analytical techniques. As on any project of this type, there were chromatographic peaks which could not be identified. Although none were considered sufficiently large or frequent to justify further investigation within the constraints of this project, the significance of their presence is not known at this time.

In general, for those compounds which were identified, the numbers of compounds found in EEWTP finished waters for all phases of operation were less than for the local waters. The percentage of individual SOC searches with positive (quantifiable) results was less for EEWTP Phase IB and IIA waters than for the local plants. During Phase IA, however, the percentage of quantified findings was higher than the highest local plant: 17 percent versus 14 percent. Many of the additional positive findings were associated with bromoform, a THM present at very low concentrations, as previously discussed.

In conclusion, the SOC analyses conducted during this project did not indicate any notable concern with respect to the suitability of EEWTP finished water as a drinking supply. In general, the water compared favorably to the local supply, particularly with respect to chlorinated organic species, primarily because of the use of GAC and alternative disinfection practices at the EEWTP. This was particularly noticeable with the process combination utilized during Phase IIA.



## SECTION 8

### TOXICOLOGICAL PARAMETERS

#### INTRODUCTION

The two toxicological assays conducted during the project, the Ames Mutagenicity test and the Mammalian Cell Transformation assay, are most commonly associated with testing compounds or mixtures of compounds for carcinogenic potential. They are in vitro screening tests used to determine whether chemicals cause mutations in bacteria (Ames test) or transform mammalian cells in culture into cells morphologically similar to malignant ones (mammalian transformation assay).

Both assays are recommended as Phase 1 in vitro toxicity tests in the National Research Council's three tiered testing program for reused water; see Table 9.8-1. (NRC, 1982). Additional Phase 1 tests are in vitro gene mutations in mammalian cells, in vivo (whole animal) studies to detect acute toxicity including teratogenicity, and toxicity effects after repeated oral doses for two-weeks. The tests in Phases 2 and 3 include a 90-day sub-chronic study, a test for reproductive toxicity and a chronic lifetime feeding study in a rodent. Full assessment of all three phases would be very costly, amounting to at least several million dollars and requiring up to three years to complete; this is well beyond the authority and scope of this project.

Mutagenicity assays, like the Ames test, have proliferated recently because one of the longest standing hypotheses of chemical carcinogenesis is based on somatic cell mutation as the causal event in transforming normal cells to the malignant state. Since the introduction of the Ames test many other short-term mutation assays have been developed for screening purposes. The Ames test, however, is still the one most widely used. Cellular transformation assays have not been tested with as many different carcinogens and non-carcinogens as the Ames test, but they utilize mammalian cell systems which are on a higher order of biochemical and molecular complexity than the bacteria used in the Ames test. This may make mammalian cell transformation more relevant to the study of mutagenesis and carcinogenesis in humans.

## Toxicological Parameters

TABLE 9.8-1  
NRC RECOMMENDED  
TOXICITY TESTING FOR REUSED WATER

### Phase 1

Mutagenicity  
In Vitro Transformation

Acute Toxicity  
Teratogenicity  
Short-term, repeated dose studies--14-day  
(includes cytogenetics assay)

### Phase 2

Subchronic 90-day study in at least one  
rodent species, preferably in two species  
Reproductive Toxicity

### Phase 3

Chronic lifetime feeding study in  
one species of rodent

## AMES TEST

In the Ames test, mutations are detected in histidine-requiring strains of Salmonella typhimurium. Salmonella tester bacteria lacking the proper sequence of DNA necessary to biosynthesize histidine, an amino acid which is required for growth and cell division, will not form visible colonies on the histidine-deficient agar medium used in the Ames test. When the proper DNA sequence is altered by a specific mutation, histidine synthesis is restored and these revertant cells will grow in the medium forming countable (visible) colonies. Spontaneous revertants form colonies in the absence of the test sample extract. When sample extract is incorporated into the medium with the bacteria, additional cells may revert from exposure to chemicals in the extract as well as from the spontaneous mechanism. Collectively, both types of revertants are termed the total revertants which are counted from the incorporation plates with sample extract added. Spontaneous revertants are counted from similar plates poured on the same day and using the same strain cultures as the incorporation plates but without the addition of the sample extract.

Two independent criteria were applied to Ames test results for classifying samples as being "positive" or "negative" for mutagenicity. The first, mutagenic ratio, is the most common measure of mutagenicity. A sample is considered mutagenic in a particular tester strain if the ratio of the total revertants to spontaneous revertants is greater than or equal to 2.0 at the

## Toxicological Parameters

highest non-toxic dose tested. Usually, the most concentrated dose on the linear portion of the dose-response curve is selected to calculate the mutagenic ratio. The criteria was modified in this study by choosing the dose with the highest average revertants per plate to calculate the ratio. As a general rule, the greatest number of revertants was found at the highest extract dose tested in project samples.

A second criteria called the specific activity was also calculated and used to determine if a sample was positive or negative. The specific activity is the number of net revertants per unit volume of sample tested, determined by the slope of an appropriate portion of the dose-response curve. For this project, specific activity was defined as the slope of the least squares regression through all points of the dose-response plot. Total revertants per plate were plotted against the dose and the specific activity calculated in units of revertants/liter. A sample was considered positive if the 95% confidence interval of the slope was greater than zero.

Agreement between specific activity and mutagenic ratio results was not always observed as shown in Table 9.8-2. However, the paired results for each sample tested in Phase IA indicate that qualitative agreement in terms of being positive or negative for mutagenicity was achieved in 62 to 80 percent of the samples depending on which tester strain was used.

TABLE 9.8-2  
COMPARISON OF MUTAGENIC RATIO AND SPECIFIC ACTIVITY  
IN PHASE IA RESULTS

<u>Tester Strain</u>	<u>No. of Samples</u>	<u>SA+/MR+</u>	<u>SA-/MR+</u>	<u>SA+/MR-</u>	<u>SA-/MR-</u>	<u>% SA Agrees with MR</u>
TA98	109	47	1	21	40	80
TA98+M.A.	101	28	2	22	49	76
TA100	114	34	0	43	37	62
TA100+M.A.	108	15	0	32	61	70

SA = specific activity; MR = mutagenic ratio; + = positive; - = negative;  
M.A. = metabolic activation using S9 preparation

Dose was calculated as the equivalent liters of water applied to an assay plate. The volume of extract exposed to the bacteria was usually 250  $\mu$ l, but this amount actually represented the equivalent of some percentage of the total water sample volume initially concentrated through the XAD adsorbent resins. For example, if 100 liters were filtered and the resulting acetone eluate was reduced to 1 ml, each 250  $\mu$ l inoculum from this undiluted extract would be equivalent to 25 L of water sample. Undiluted extract was too toxic to the bacteria to be directly applied in the assay. Therefore, the initial extracts were diluted in dimethyl sulfoxide to reduce toxicity effects. Generally, the

## Toxicological Parameters

highest equivalent concentration exposed to the bacteria ranged between 4.0 to 8.0 L/plate. In most assays, four doses were tested with each strain, with and without metabolic activation. Assays were included in the evaluation if at least three doses were tested and the total water volume filtered through XAD resins was greater than 30 L.

Some chemical mutagens and carcinogens require metabolic activation *in vivo*. Mammalian metabolism is incorporated into the *in vitro* Ames test by adding mammalian liver homogenates directly to the petri plates. The liver homogenate contains microsomal enzymes which may activate or deactivate chemicals, producing greater or fewer revertants compared to the plates without the enzymes. In many cases, the addition of liver homogenate has no effect either way. The PCB - induced rat liver homogenate, called S9, used in project assays tended to reduce the mutagenicity in sample concentrates.

A discussion of interpreting project Ames test data follows Phase IIA results.

### PHASE IA RESULTS

Tables 9.8-3 and 9.8-4 summarize the comparison of finished waters. Phase IA EEWTP finished water samples were concentrated from the post-chlorination process stream during the period of 3 June 1981 through 16 March 1982. Samples were concentrated from post-disinfection sites at the three monitored plants in the MWA supply system. For purposes of comparison, only samples taken from the Phase IA period are included in the analysis. An additional evaluation was conducted, comparing the data for each local WTP from the entire project time period to the EEWTP finished water results in each phase. Conclusions were not altered based on this evaluation.

Tables 9.8-3 and 9.8-4 show statistical parameters including the mean, standard deviation, median and range, for both the specific activities and mutagenic ratios. Also, the percentage of positive assays by both specific activity and mutagenic ratio criteria are shown. Table 9.8-5 ranks the finished water sites by increasing value of the statistical parameters and percentage of positives. The EEWTP had the lowest mean, median, and maximum specific activities and mutagenic ratios, except for the median specific activity for TA 100 and the maximum mutagenic ratio for TA 100 with metabolic activation, where WTP 3 was lower in both cases. The EEWTP also had the lowest percentage of positive assays by both specific activity and mutagenic ratio criteria except for mutagenic ratio in TA 100 with metabolic activation where WTP3 was lowest.

### PHASE IB RESULTS

Large volume sampling (100 liters) at the EEWTP and local WTP finished water sites was conducted between 17 March 1982 and 29 June 1982. Statistical parameter values in Tables 9.8-6 and 9.8-7 were generally lower than in Phase IA for corresponding site/tester strain combinations. The rankings in Table 9.8-8 indicate that the EEWTP had the lowest specific activities and mutagenic ratios except for maximum mutagenic ratio in TA 98 with metabolic activation where WTP3 was lowest. Addition of S9 metabolic activation mixture reduced specific activity in IA samples by approximately

TABLE 9.8-3  
 PHASE IA AMES TEST RESULTS  
 TESTER STRAIN TA98 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<b>TA98 Without Metabolic Activation</b>				
Number of Assays	28	28	25	28
Number of Positives by Specific Activity <sup>1</sup>	7 (25%)	19 (68%)	22 (88%)	20 (71%)
Mean Activity (revertants/L)	2	8	10	6
Standard Deviation	2	9	12	6
Median Activity	1	4	6	4
Range	0-7	0-34	0-44	0-27
Number of Positives by Mutagenic Ratio <sup>2</sup>	2 (7%)	15 (54%)	17 (68%)	14 (50%)
Mean Mutagenic Ratio	1.5	3.0	3.4	2.2
Standard Deviation	0.4	2.0	2.7	0.9
Median Mutagenic Ratio	1.5	2.1	2.6	2.0
Range	0.6-2.8	1.1-8.1	0.8-14.5	1-5.1
<b>TA98 With Metabolic Activation</b>				
Number of Assays	26	26	24	25
Number of Positives by Specific Activity	3 (12%)	16 (62%)	16 (67%)	14 (56%)
Mean Activity (revertants/L)	1	5	6	3
Standard Deviation	1	7	6	3
Median Activity	1	3	4	3
Range	0-3	0-32	0-25	0-11
Number of Positives by Mutagenic Ratio	0 (0%)	12 (46%)	8 (33%)	11 (44%)
Mean Mutagenic Ratio	1.3	2.5	2.4	1.9
Standard Deviation	0.3	1.8	1.8	0.7
Median Mutagenic Ratio	1.4	1.8	1.8	1.7
Range	0.6-1.8	1.1-9.4	0.9-8.7	1-3.6

1. The specific activity was defined as the slope of the least-squares regression line through the dose-response plot. An assay was positive if the 95% confidence interval of the slope was greater than zero. An assay with a negative specific activity (negative slope) was assigned a specific activity of zero (0) for purposes of calculating statistical parameters.

2. The mutagenic ratio was defined as the ratio of total to spontaneous revertants at the dose with the greatest average number of total revertants. An assay was scored positive if the ratio was greater than or equal to 2.0.

TABLE 9.8-4  
PHASE IA AMES TEST RESULTS  
TESTER STRAIN TA100 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<u>TA100 Without Metabolic Activation</u>				
Number of Assays	28	30	28	28
Number of Positives by Specific Activity <sup>1</sup>	17 (61%)	22 (73%)	21 (75%)	17 (61%)
Mean Activity (revertants/L)	13	22	35	22
Standard Deviation	12	29	47	24
Median Activity	11	12	16	9
Range	0-37	0-128	0-178	0-80
<u>Number of Positives by Mutagenic Ratio<sup>2</sup></u>				
Mean Mutagenic Ratio	6 (21%)	9 (30%)	10 (36%)	9 (32%)
Standard Deviation	1.6	1.9	2.0	1.7
Median Mutagenic Ratio	0.6	1.0	1.0	0.7
Range	0.9-3.5	1.1-5.3	1-4.3	1-4.2
<u>TA100 With Metabolic Activation</u>				
Number of Assays	26	29	26	27
Number of Positives by Specific Activity	8 (31%)	13 (45%)	14 (54%)	13 (48%)
Mean Activity (revertants/L)	7	11	24	11
Standard Deviation	7	12	46	10
Median Activity	5	6	9	8
Range	0-33	0-46	0-237	0-35
<u>Number of Positives by Mutagenic Ratio</u>				
Mean Mutagenic Ratio	2 (8%)	6 (21%)	5 (19%)	2 (7%)
Standard Deviation	1.4	1.5	1.6	1.4
Median Mutagenic Ratio	0.3	0.6	0.6	0.3
Range	1.1-2.4	1.1-3.9	1-3.6	1-2.1

1. The specific activity was defined as the slope of the least-squares regression line through the dose-response curve. An assay was positive if the 95% confidence interval of the slope was greater than zero. An assay with a negative specific activity (negative slope) was assigned a specific activity of zero (0) for purposes of calculating statistical parameters.

2. The mutagenic ratio was defined as the ratio of total to spontaneous revertants at the dose with the greatest average number of total revertants. An assay was scored positive if the ratio was greater than or equal to 2.0.

# Toxicological Parameters

TABLE 9.8-5  
PHASE IA AMES TEST RESULTS  
RANKING OF SPECIFIC ACTIVITY AND MUTAGENIC RATIO

Strain	Parameter	Lowest Value			Highest Value
TA98	% Positive S.A.	EEWTP	WTP1	WTP3	WTP2
	Mean S.A.	EEWTP	WTP3	WTP1	WTP2
	Median S.A.	EEWTP	WTP1	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
	%Positive M.R.	EEWTP	WTP3	WTP1	WTP2
	Mean M.R.	EEWTP	WTP3	WTP1	WTP2
	Median M.R.	EEWTP	WTP3	WTP1	WTP2
	Maximum M.R.	EEWTP	WTP3	WTP1	WTP2
TA98 + M.A.	%Positive S.A.	EEWTP	WTP3	WTP1	WTP2
	Mean S.A.	EEWTP	WTP3	WTP1	WTP2
	Median S.A.	EEWTP	WTP3	WTP1	WTP2
	Maximum S.A.	EEWTP	WTP3	WTP2	WTP1
	%Positive M.R.	EEWTP	WTP2	WTP3	WTP1
	Mean M.R.	EEWTP	WTP3	WTP2	WTP1
	Median M.R.	EEWTP	WTP3	WTP1	WTP2
	Maximum M.R.	EEWTP	WTP3	WTP2	WTP1
TA100	% Positive S.A.	EEWTP	& WTP3	WTP1	WTP2
	Mean S.A.	EEWTP	WTP1 &	WTP3	WTP2
	Median S.A.	WTP3	EEWTP	WTP1	WTP2
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
	% Positive M.R.	EEWTP	WTP1	WTP3	WTP2
	Mean M.R.	EEWTP	WTP3	WTP1	WTP2
	Median M.R.	EEWTP	& WTP1	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP3	WTP2	WTP1
TA100 + M.A.	% Positive S.A.	EEWTP	WTP1	WTP3	WTP2
	Mean S.A.	EEWTP	WTP1	WTP3	WTP2
	Median S.A.	EEWTP	WTP1	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
	% Positive M.R.	WTP3	EEWTP	WTP2	WTP1
	Mean M.R.	EEWTP	& WTP3	WTP1	WTP2
	Median M.R.	EEWTP	& WTP1	WTP2 &	WTP3
	Maximum M.R.	WTP3	EEWTP	WTP2	WTP1

S.A. = Specific Activity; M.R. = Mutagenic Ratio; M.A. = Metabolic Activation;  
& indicates equal value

TABLE 9.8-6

PHASE IB AMES TEST RESULTS  
TESTER STRAIN TA98 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<b>TA98 Without Metabolic Activation</b>				
Number of Assays	24	27	21	24
Number of Positives by Specific Activity	2 (8%)	20 (74%)	18 (86%)	17 (71%)
Mean Activity (revertants/L)	1	3	4	4
Standard Deviation	1	3	3	3
Median Activity	<1	3	4	2
Range	0-7	0-15	1-12	0-14
<b>Number of Positives by Mutagenic Ratio</b>				
Mean Mutagenic Ratio	1 (4%)	10 (37%)	12 (57%)	11 (46%)
Standard Deviation	1.3	2.3	2.5	2.4
Median Mutagenic Ratio	0.5	1.4	1.1	1.4
Range	1.1	1.8	2.3	1.9
	0.8-3.0	0.9-7.8	1.2-5.2	1.1-6.6
<b>TA98 With Metabolic Activation</b>				
Number of Assays	24	27	21	24
Number of Positive by Specific Activity	1 (4%)	11 (41%)	13 (62%)	12 (50%)
Mean Activity (revertants/L)	1	2	3	2
Standard Deviation	1	3	3	2
Median Mutagenic Ratio	<1	2	2	2
Range	0-3	0-11	0-15	0-7
<b>Number of Positives by Mutagenic Ratio</b>				
Mean Mutagenic Ratio	2 (8%)	7 (26%)	8 (38%)	5 (21%)
Standard Deviation	1.4	2.1	2.0	1.8
Median Mutagenic Ratio	0.9	1.6	0.8	0.8
Range	1.2	1.4	1.7	1.6
	1.0-5.2	0.8-8.0	1.1-5.0	1.1-4.3



TABLE 9.8-7

PHASE IB AMES TEST RESULTS  
TESTER STRAIN TA100 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<u>TA100 Without Metabolic Activation</u>				
Number of Assays	22	27	19	24
Number of Positives by Specific Activity	4 (18%)	17 (63%)	15 (79%)	15 (63%)
Mean Activity (revertants/L)	3	7	11	10
Standard Deviation	4	5	8	10
Median Activity	1	5	9	7
Range	0-20	0-23	1-28	0-40
Number of Positives by Mutagenic Ratio	0 (0%)	1 (4%)	5 (26%)	2 (8%)
Mean Mutagenic Ratio	1.1	1.4	1.6	1.5
Standard Deviation	0.2	0.3	0.5	0.6
Median Mutagenic Ratio	1.1	1.3	1.4	1.3
Range	0.9-1.7	1.0-2.1	1.0-2.8	0.9-3.3
<u>TA100 With Metabolic Activation</u>				
Number of Assays	22	27	19	24
Number of Positives by Specific Activity	3 (14%)	11 (41%)	11 (58%)	12 (50%)
Mean Activity (revertants/L)	2	4	6	7
Standard Deviation	3	3	4	5
Median Activity	1	4	6	5
Range	0-10	0-13	0-15	0-19
Number of Positives by Mutagenic Ratio	0 (0%)	0 (0%)	0%	1 (4%)
Mean Mutagenic Ratio	1.2	1.3	1.3	1.4
Standard Deviation	0.2	0.2	0.2	0.3
Median Mutagenic Ratio	1.2	1.3	1.4	1.3
Range	0.9-1.4	1.0-1.7	1.0-1.9	1.1-2.1

# Toxicological Parameters

TABLE 9.8-8  
PHASE IB AMES TEST RESULTS  
RANKING OF SPECIFIC ACTIVITY AND MUTAGENIC RATIO

Strain	Parameter	Lowest Value		Highest Value	
TA98	% Positive S.A.	EEWTP	WTP3	WTP1	WTP2
	Mean S.A.	EEWTP	WTP1	WTP2 &	WTP3
	Median S.A.	EEWTP	WTP3	WTP1	WTP2
	Maximum S.A.	EEWTP	WTP2	WTP3	WTP1
	% Positive M.R.	EEWTP	WTP1	WTP3	WTP2
	Mean M.R.	EEWTP	WTP1	WTP3	WTP2
	Median M.R.	EEWTP	WTP1	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP2	WTP3	WTP1
	% Positive S.A.	EEWTP	WTP1	WTP3	WTP2
	Mean S.A.	EEWTP	WTP1 &	WTP3	WTP2
TA98 + M.A.	Median S.A.	EEWTP	WTP1 &	WTP2 &	WTP3
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
	% Positive M.R.	EEWTP	WTP3	WTP1	WTP2
	Mean M.R.	EEWTP	WTP3	WTP2	WTP1
	Median M.R.	EEWTP	WTP1	WTP3	WTP2
	Maximum M.R.	WTP3	WTP2	EEWTP	WTP1
	% Positive S.A.	EEWTP	WTP1 &	WTP3	WTP2
	Mean S.A.	EEWTP	WTP1	WTP3	WTP2
	Median S.A.	EEWTP	WTP1	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP1	WTP2	WTP3
TA100	% Positive M.R.	EEWTP	WTP1	WTP3	WTP2
	Mean M.R.	EEWTP	WTP1	WTP3	WTP2
	Median M.R.	EEWTP	WTP1 &	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP1	WTP2	WTP3
	% Positive S.A.	EEWTP	WTP1	WTP3	WTP2
	Mean S.A.	EEWTP	WTP1	WTP3	WTP2
	Median S.A.	EEWTP	WTP1	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP1	WTP2	WTP3
	% Positive M.R.	EEWTP	WTP1	WTP3	WTP2
	Mean M.R.	EEWTP	WTP1	WTP3	WTP2
TA100 + M.A.	Median M.R.	EEWTP	WTP1 &	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP1	WTP2	WTP3
	% Positive S.A.	EEWTP	WTP1	WTP3	WTP2
	Mean S.A.	EEWTP	WTP1	WTP2	WTP3
	Median S.A.	EEWTP	WTP1	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP1	WTP2	WTP3
	% Positive M.R.	EEWTP &	WTP1 &	WTP2	WTP3
	Mean M.R.	EEWTP	WTP1 &	WTP2	WTP3
	Median M.R.	EEWTP	WTP1 &	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP1	WTP2	WTP3

KEY: S.A. = Specific Activity  
M.R. = Mutagenic Ratio

M.A. = Metabolic Activation  
& = Indicates Equal Value

## Toxicological Parameters

10 revertants/L or 43 percent of the specific activity of samples without S9 activation. In Phase IB samples, S9 reduced specific activity by 3 revertants/L or a reduction of 38 percent of the specific activity of samples without activation.

### PHASE IIA RESULTS

Tables 9.8-9 through 9.8-11 summarize Phase IIA Ames test results for finished water samples concentrated between 20 July 1982 and 18 February 1983. The statistical parameter rankings in Table 9.8-11 reveal that the EEWTP again had the lowest values of the mutagenic parameters.

### DATA INTERPRETATION

Although the local treatment plants had higher specific activities and mutagenic ratios than the EEWTP, this does not mean that they represent any public health risk, particularly with respect to cancer. The National Research Council has stated that, "Because of the complex nature of water concentrates, the assumption that positive results in short-term tests are predictive of carcinogenicity may or may not be valid (NAS, 1982)." Batteries of short-term toxicity tests often including the Ames test, have demonstrated good correlation to carcinogenicity testing using individual chemicals. But the lack of comparative toxicity data using concentrated water samples simultaneously in short-term in vitro and chronic in vivo studies has resulted in too small a database to permit definitive conclusions regarding the predictive nature of short-term tests for complex mixtures.

Any attempt to reach a consensus on the application of short-term toxicity tests as predictive tools must address the problems associated with preparing concentrated samples. The NRC (NAS, 1982) noted the following problems associated with preparing concentrated water samples for toxicity testing:

- The changing consistency of samples may affect the reproducibility of results.
- Additive, synergistic or antagonistic effects of mixture components could vary with individual samples and change with time.
- Chemical and physical stability of concentrates may vary over time.

These problems are potentially significant if samples must be prepared for long-term toxicity studies, especially when sample preparation must be completed well in advance of the end of actual testing. The entire question of how to produce representative extracts from large volumes of water is still under investigation by many research groups. Project extracts were tested in the Ames test as soon as possible, usually within two weeks of sampling.

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TABLE 9.8-9  
PHASE IIA AMES TEST RESULTS  
TESTER STRAIN TA98 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<b>TA98 Without M.A.</b>				
Number of Assays	19	15	12	18
Number of Positives by Specific Activity	2 (11%)	10 (67%)	7 (58%)	12 (67%)
Mean Activity (revertants/L)	1	3	4	3
Standard Deviation	1	3	4	2
Median Activity	1	2	2	2
Range	0-2	0-9	0-11	0-8
<b>Number of Positives by Mutagenic Ratio</b>				
Mean Mutagenic Ratio	0 (0%)	6 (40%)	5 (42%)	9 (50%)
Standard Deviation	1.2	2.3	2.6	2.1
Median Mutagenic Ratio	0.3	1.3	1.9	0.9
Range	1.1	1.7	1.9	1.9
	0.9-1.7	1.0-5.0	1.2-7.9	0.9-3.9
<b>TA98 With M.A.</b>				
Number of Assays	18	14	9	16
Number of Positives by Specific Activity	4 (22%)	10 (71%)	7 (78%)	7 (44%)
Mean Activity (revertants/L)	1	3	4	2
Standard Deviation	1	3	4	2
Median Activity	1	2	4	1
Range	0-2	0-9	0-14	0-8
<b>Number of Positives by Mutagenic Ratio</b>				
Mean Mutagenic Ratio	0 (0%)	5 (36%)	5 (56%)	4 (25%)
Standard Deviation	1.3	1.8	2.5	1.7
Median Mutagenic Ratio	0.2	0.6	1.2	0.9
Range	1.3	1.8	2.1	1.3
	1.0-1.7	0.9-3.3	1.1-4.6	0.9-3.4

TABLE 9.8-10

PHASE IIA AMES TEST RESULTS  
 TESTER STRAIN TA100 WITH AND WITHOUT METABOLIC ACTIVATION

	EEWTP	WTP1	WTP2	WTP3
<b>TA100 Without M.A.</b>				
Number of Assays	18	14	12	17
Number of Positives by Specific Activity	2 (11%)	12 (86%)	5 (42%)	11 (65%)
Mean Activity (revertants/L)	1	12	9	9
Standard Deviation	2	8	10	7
Median Activity	0	12	4	9
Range	1-5	0-24	0-30	0-24
<b>Number of Positives by Mutagenic Ratio</b>				
	0 (0%)	2 (14%)	2 (17%)	3 (18%)
Mean Mutagenic Ratio	1.1	1.6	1.6	1.5
Standard Deviation	0.2	0.4	0.6	0.5
Median Mutagenic Ratio	1.1	1.5	1.4	1.5
Range	0.9-1.8	1.1-2.5	1.0-2.8	1.0-3.0
<b>TA100 With M.A.</b>				
Number of Assays	17	13	9	14
Number of Positives by Specific Activity	1 (6%)	9 (69%)	3 (33%)	9 (64%)
Mean Activity (revertants/L)	1	7	6	5
Standard Deviation	2	5	6	4
Median Activity	0	5	7	5
Range	0-5	1-19	0-16	0-16
<b>Number of Positives by Mutagenic Ratio</b>				
	0 (0%)	1 (8%)	0 (0%)	0 (0%)
Mean Mutagenic Ratio	1.1	1.3	1.4	1.3
Standard Deviation	0.2	0.1	0.3	0.2
Median Mutagenic Ratio	1.1	1.3	1.4	1.3
Range	0.9-1.5	1.0-2.5	1.1-1.8	1.0-1.9

# Toxicological Parameters

TABLE 9.8-11  
PHASE IIA AMES TEST RESULTS  
RANKING OF SPECIFIC ACTIVITY AND MUTAGENIC RATIO

Strain	Parameter	Lowest Value			Highest Value
TA98	% Positive S.A.	EEWTP	WTP2	WTP1	WTP3
	Mean S.A.	EEWTP	WTP1 &	WTP3	WTP2
	Median S.A.	EEWTP	WTP1 &	WTP2 &	WTP3
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
	% Positive M.R.	EEWTP	WTP1	WTP2	WTP3
	Mean M.R.	EEWTP	WTP3	WTP1	WTP2
	Median M.R.	EEWTP	WTP1	WTP2 &	WTP3
	Maximum M.R.	EEWTP	WTP3	WTP1	WTP2
	% Positive S.A.	EEWTP	WTP3	WTP1	WTP2
	Mean S.A.	EEWTP	WTP3	WTP1	WTP2
	Median S.A.	EEWTP &	WTP3	WTP1	WTP2
	Maximum S.A.	EEWTP	WTP3	WTP1	WTP2
TA98 + M.A.	% Positive M.R.	EEWTP	WTP3	WTP1	WTP2
	Mean M.R.	EEWTP	WTP3	WTP1	WTP2
	Median M.R.	EEWTP &	WTP3	WTP1	WTP2
	Maximum M.R.	EEWTP	WTP1	WTP3	WTP2
	% Positive S.A.	EEWTP	WTP2	WTP3	WTP1
	Mean S.A.	EEWTP	WTP2 &	WTP3	WTP1
	Median S.A.	EEWTP	WTP2	WTP3	WTP1
	Maximum S.A.	EEWTP	WTP1 &	WTP3	WTP2
	% Positive M.R.	EEWTP	WTP1	WTP2	WTP3
	Mean M.R.	EEWTP	WTP3	WTP1 &	WTP2
	Median M.R.	EEWTP	WTP2	WTP1 &	WTP3
	Maximum M.R.	EEWTP	WTP1	WTP2	WTP3
TA100	% Positive S.A.	EEWTP	WTP2	WTP3	WTP1
	Mean S.A.	EEWTP	WTP2 &	WTP3	WTP1
	Median S.A.	EEWTP	WTP2	WTP3	WTP1
	Maximum S.A.	EEWTP	WTP1 &	WTP3	WTP2
	% Positive M.R.	EEWTP	WTP1	WTP2	WTP3
	Mean M.R.	EEWTP	WTP3	WTP1 &	WTP2
	Median M.R.	EEWTP	WTP2	WTP1 &	WTP3
	Maximum M.R.	EEWTP	WTP1	WTP2	WTP3
	% Positive S.A.	EEWTP	WTP2	WTP3	WTP1
	Mean S.A.	EEWTP	WTP3	WTP2	WTP1
	Median S.A.	EEWTP	WTP1 &	WTP3	WTP2
	Maximum S.A.	EEWTP	WTP2 &	WTP3	WTP1
TA100 + M.A.	% Positive M.R.	EEWTP &	WTP2 &	WTP3	WTP1
	Mean M.R.	EEWTP	WTP1 &	WTP3	WTP2
	Median M.R.	EEWTP	WTP1 &	WTP3	WTP2
	Maximum M.R.	EEWTP	WTP2	WTP3	WTP1

KEY: S.A. = Specific Activity  
M.R. = Mutagenic Ratio

M.A. = Metabolic Activation  
& = Indicates Equal Value

## Toxicological Parameters

Table 9.8-12 lists the major published studies evaluating the toxicity of water samples collected from various stages of wastewater and drinking water treatment processes. The majority of the wastewater references are studies conducted on advanced treatment facilities which have processes similar to the ones operated at the EEWTP. The most striking feature of this table is the lack of uniformity or standardization in sample preparation. In order to obtain positive responses in *in vitro* and *in vivo* biological assays, many of the investigators concentrated large volumes of water by using such methods as solid sorbents, liquid - liquid extraction, reverse osmosis and freeze-drying.

Even when different investigators used the same solid sorbent for concentration, such as XAD-2 resins, there were several different organic solvents employed to elute the concentrated organic components from the sorbent medium. Differences in concentration and extraction methods will affect the recovery of organics, including those potentially toxic compounds which may be present in the unconcentrated samples. Tests conducted during this project indicate that the XAD resin columns used adsorbed 15-30 percent of the column influent total organic carbon and 10-54 percent of the total organic halide.

The absence of uniformity in preparing concentrates makes comparisons of results from this project to most other independent studies impractical. Most of the studies listed in Table 9.8-12 reported positive results in the test system used, but criteria for determining positive and negative responses varied from study to study. Several studies which utilized procedures similar to the one selected for this study are described below.

Nestmann (1979) concentrated 200 L samples of chlorinated drinking water on XAD-2 resins which were eluted with 15 percent acetone in hexane (V/V). The extracts were reduced to dryness, redissolved in DMSO and then assayed in the Ames test system. Results were shown graphically or in tabular form. In order to calculate mutagenic ratios from the data presented in the article, spontaneous revertants were estimated from the zero dose on the dose-response graph, also presented in the article. Ratios were calculated using total revertants at a dose equivalent to 10 L/plate. Mutagenic ratios from five samples ranged between  $< 1.0$  to 12.5 and  $< 1.0$  to 5.1 for TA 98 and TA 100, respectively, both without metabolic activation.

Hooper (1978) detected specific activities between 20 and 125 revertants/L (TA 100) in San Francisco Bay area drinking waters using 38 to 270 L samples concentrated on XAD-2 and eluted with acetone. Van Rossum (1982) investigated mutagenicity in Pretoria, South Africa drinking water using the Ames test. Forty liter samples were concentrated on XAD-2 and eluted with acetone. Only samples without a free chlorine residual were extracted and assayed. The investigators did not detect any mutagenic samples with strain TA 100. Five of eighteen samples assayed with TA 98 with metabolic activation were positive (M.R.  $> 2.0$ ). The average mutagenic ratio for all samples combined was 1.7. The absence of S9 increased the mutagenicity of the extracts to eleven mutagenic samples. The average ratio without S9 addition was 2.9.

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TABLE 9.8-12 (Continued)  
 SELECTED EXAMPLES OF METHODS USED TO PREPARE ORGANIC CONCENTRATES FOR BIOLOGICAL TESTING

Water Source	Concentration Method	Extraction Solvent	Biological Testing	Reference
Surface and drinking water	Activated carbon	?	Mouse skin	Hueper, 1954
Wastewater effluent and drinking water	Unconcentrated and activated carbon	(spent carbon fed directly to rats)	Rat feedings	Van Rensburg, 1978
Wastewater effluent	1) XAD-8	1) Acetone	Ames test	McCarty, 1982
	2) Anion/cation exchange	2) Ammonium hydroxide		
	3) Ultrafiltration	3) —		
	4) Purge and trap	4) Methanol		
Wastewater effluent	Lyophilisation		Ames test and WP 2	Cumming, 1980
Drinking water	XAD-4	Acetone and methylene chloride	E. Coli	Cheh, 1980
Drinking water	XAD-4/8	Acetone and DMSO	Ames test	Kool, 1982
Drinking water	Freeze drying	—	V97 mutation	Gruener, 1980
Drinking water	XAD-2	Ether	Ames test	Glatz, 1978
Wastewater effluent	Unconcentrated	—	Ames test	Saxena, 1979

## Toxicological Parameters

The results from these studies and others listed in Table 9.8-12 indicate a wide range of mutagenic responses and amplify the conclusion that comparison of results between independent studies is impractical and not appropriate in the evaluation of finished water quality at this time.

### MAMMALIAN CELL TRANSFORMATION ASSAY

The Ames test has been widely used to screen environmental samples for mutagens and carcinogens. Many other short-term assays utilizing different test organisms and test endpoints have been developed for toxicological testing. However, no single assay is capable of detecting all carcinogens and many investigators favor using a battery of short-term tests to gather toxicological data. The use of mammalian cells, though more costly and time-consuming than bacterial systems, has the advantage of being more closely related to human cells with respect to its DNA and metabolic activities.

Over the past ten years, a number of mammalian cell culture systems have been developed in which non-malignant cells have been transformed (changed morphologically) following exposure in vitro to chemical carcinogens. Although originally developed to study the events leading to carcinogenesis, these tests show great promise as rapid tests for screening potential carcinogens. Reproducible quantitative systems utilizing cell strains and cell lines have correctly identified many carcinogens. When the transformed cells are injected into suitable hosts a high correlation with tumorigenicity is observed.

The mammalian cell transformation assay used in this project was developed by Dr. Charles Heidelberger and his co-workers. The system utilizes a fibroblastic cell line, C3H/10T1/2, derived from C3H mouse embryos. The cell line has an extremely low rate of spontaneous transformation as well as a very flat morphology, making it relatively easy to score morphologically transformed foci. In this system, morphologic cell transformation is characterized by the cells' loss of density-dependent inhibition, resulting in the formation of colonies in which the cells have piled up.

The C3H/10T1/2 cell line has been transformed with polycyclic aromatic hydrocarbons with a quantitative dose response. In addition, the cell line was found to be transformable with chemically reactive carcinogens such as N-methyl-N'-nitro-nitrosoguanidine and N-acetoxy-N-2-acetylaminofluorene, several cancer therapeutic agents, tobacco smoke condensates and hair dyes. The cell line is widely used throughout the world in carcinogenic studies.

In this assay, actively growing cells were exposed for 48 hours to three dose levels of extract concentrated from XAD resins. The extraction procedure was the same as that used for the Ames test. Each dilution was inoculated onto 20 plates. The cells were then rinsed and maintained at 37°C in 5 percent carbon dioxide for six weeks at which time the cells were stained with Giemsa and examined under a dissecting microscope for morphologically transformed foci.

Three types of foci can be identified. Type I is a focus composed of tightly packed cells. Type II foci show massive piling up into opaque multilayers in which criss-crossing is not pronounced, and Type III foci are multi-layered criss-

## Toxicological Parameters

crossed arrays of densely stained cells. Only Type II and Type III foci were scored, since it has been demonstrated that between 50 and 83 percent of these foci produce sarcomas when injected into susceptible mice (Reznikoff, 1973). If any of the sixty exposed plates (3 dilutions, 20 plates/dilution) had at least one transformed Type II or Type III foci, the assay was considered "positive."

To determine plating efficiency, cytotoxicity assays were run concurrently with the transformation assays. The test was conducted by exposing 200 cells per dish, five dishes per dilution to the test material. After incubating treated cells for 7 to 10 days, the cells were stained and the number of colonies that developed from the surviving cells were counted. Samples were tested in this assay at the same dose levels as in the transformation assays, 0.25-2.3 liter equivalents per plate. In general, the number of cells surviving treatment decreased as the dose levels increased. In some instances, no cells would survive at a given dose level. In cases where there was a positive sample in the transformation assay and no cells survived the cytotoxicity assay, the transformation frequency could not be calculated since the plating efficiency could not be calculated. Refer to Appendix A, Section 1 for more details on this test.

### PHASE IA RESULTS

Monthly XAD resin concentrations were conducted at the EEWTP and local WTP finished water sites between 1 July 1981 and 16 March 1982. Table 9.8-13 summarizes the finished water data for Phase IA. Summary statistics such as mean, standard deviation and median transformation frequency could not be calculated because of the small number of positive samples.

In this phase of the project, transforming activity was present in extracts obtained from all four finished water sites. The small number of samples tested and the absence of frequency data for WTP3 makes it impossible to rank the treatment plants with respect to frequency of transformation.

### PHASE IB RESULTS

Monthly XAD resin concentrations at the finished water sites were conducted between 24 March 1982 and 29 June 1982. Table 9.8-14 summarizes the finished water data for Phase IB. Only one sample was positive during this phase of the study. The transformation frequency for the positive extract concentration at WTP3 was  $0.75 \times 10^{-3}$  per surviving cell.

### PHASE IIA RESULTS

Monthly XAD resin concentrations were conducted between 27 July and 29 December 1982. Table 9.8-15 summarizes the finished water data for Phase IIA. During this phase of the study, one extract from WTP1 was positive. The transformation frequency for this extract was  $1.1 \times 10^{-3}$  per surviving cell.

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TABLE 9.8-13  
PHASE IA TRANSFORMATION ASSAY RESULTS

	REWTP		WTP1		WTP2		WTP3	
No. of Assays Performed <sup>1</sup>	7		6		8		7	
No. of Positive Assays <sup>2</sup>	2		1		3		1	
Positive Assay # 1								
a) Dilutions tested (liters/plate) <sup>3</sup>	0.6	1.2	2.5	0.6	1.2	2.3	0.6	1.2
b) No. of plates scored <sup>4</sup>	14	15	10	14	10	6	9	13
c) No. of Type II or III transformed foci/no. plates scored	2/14	0/15	0/10	1/14	0/10	1/16	0/9	1/13
d) Average no. of foci/plate	0.14	0	0	0.07	0	0.17	0	0.08
e) Surviving cells/plate <sup>5</sup>	176	—	—	218	—	126	—	20
f) Transformation frequency <sup>6</sup> (Average no. of foci/ 1000 surviving cells)	0.80	—	—	0.32	—	1.3	—	4.0
Positive Assay # 2								
a) Dilutions tested (liters/plate) <sup>3</sup>	.5	.75	1.0	—	—	—	.4	.8
b) No. of plates scored <sup>4</sup>	14	11	7	—	—	—	14	12
c) No. of Type II or III transformed foci/no. plates scored	1/14	0/11	0/7	—	—	—	4/14	0/11
d) Average no. of foci/plate	0.07	0	0	—	—	—	0.29	0
e) Surviving cells/plate <sup>5</sup>	112	—	—	—	—	—	NC	—
f) Transformation frequency <sup>6</sup> (Average no. of foci/ 1000 surviving cells)	0.62	—	—	—	—	—	NC	—
Positive Assay # 3								
a) Dilutions tested (liters/plate) <sup>3</sup>	—	—	—	—	—	—	.4	.9
b) No. of plates scored <sup>4</sup>	—	—	—	—	—	—	4	6
c) No. of Type II or III transformed foci/no. plates scored	—	—	—	—	—	—	2/4	1/6
d) Average no. of foci/plate	—	—	—	—	—	—	0.5	0.17
e) Surviving cells/plate <sup>5</sup>	—	—	—	—	—	—	NC	NC
f) Transformation frequency <sup>6</sup> (Average no. of foci/ 1000 surviving cells)	—	—	—	—	—	—	NC	NC

1. An assay was performed on each extract concentrated from XAD resins, as discussed for the Ames test. Each extract was tested in three dilutions, and each dilution was inoculated into 20 plates, containing the cells (C3H/10T1/2).
2. If any of the 60 exposed plates (3 dilutions, 20 plates/dilution) had at least one transformed foci, the assay was considered "positive."
3. Dilutions are in units of equivalent liters of finished water per plate, as discussed for the Ames test.
4. Although twenty plates per dilution were tested, fewer than twenty were generally scored for foci because of toxicity which destroyed all the cells on some of the plates.
5. The percentage of surviving cells in the cytotoxicity test was determined (usually between 0 to 20 percent of the 200 cells exposed to each dilution survived treatment). This value was used to calculate the number of surviving cells per plate in the transformation assay. For example, if the survival efficiency was 10 percent, then the surviving cells/plate were estimated to be 200 (0.1)(2000 cells/plate). Each plate in the transformation assay was seeded with 2000 cells. NC is reported where no plating efficiency data was available.
6. Transformation Frequency =  $\frac{\text{Average no. of foci/plate}}{\text{Surviving cells/plate}} \times 1000$
7. NC = Not Calculated.

# Toxicological Parameters

TABLE 9.8-14  
PHASE IB TRANSFORMATION ASSAY RESULTS

	EEWTP	WTP1	WTP2	WTP3
No. of Assays Performed <sup>1</sup>	8	8	8	8
No. of Positive Assays <sup>2</sup>	0	0	0	1
Positive Assay # 1				
a) Dilutions tested (liters/plate) <sup>3</sup>	—	—	—	.4
b) No. of plates scored <sup>4</sup>	—	—	—	10
c) No. of Type II or III transformed foci/no. plates scored	—	—	—	0/10
d) Average no. of foci/plate	—	—	—	0
e) Surviving cells/plate <sup>5</sup>	—	—	—	0
f) Transformation frequency <sup>6</sup>	—	—	—	0.08
(Average no. of foci/ 1000 surviving cells)	—	—	—	102
				0.78

<sup>1</sup> through <sup>6</sup>: See Table 9.8-13 for footnotes.

# Toxicological Parameters

TABLE 9.8-15  
PHASE IIA TRANSFORMATION ASSAY RESULTS

	EEWIP	WTP1	WTP2	WTP3
No. of Assays Performed <sup>1</sup>	9	9	9	9
No. of Positive Assays <sup>2</sup>	0	1	0	0
Positive Assay # 1				
a) Dilutions tested (liters/plate) <sup>3</sup>	—	.4	—	—
b) No. of plates scored <sup>4</sup>	—	17	—	—
c) No. of Type II or III transformed foci/no. plates scored	—	0/17	—	—
d) Average no. of foci/plate	—	0	—	—
e) Surviving cells/plate <sup>5</sup>	—	0	—	—
f) Transformation frequency <sup>6</sup>	—	—	—	—
(Average no. of foci/ 1000 surviving cells)	—	—	—	—

<sup>1</sup> through <sup>6</sup>. See Table 9.8-13 for footnotes.

### DATA INTERPRETATION

It must be emphasized that there is not enough information at this time to extend mammalian cell culture data for purposes of predicting relative health risks in humans. Past work with in vitro mammalian transformation assays has been primarily associated with the prediction of potential carcinogenicity of single compounds. The use of mammalian cell transformation assays to predict the potential carcinogenicity of complex environmental mixtures by concentrating large volumes is relatively limited.

In terms of cell transformation frequencies observed during this project, the results did not suggest any significant increase in transformation frequency at any finished water site relative to the others.

With respect to results from individual operating phases (Tables 9.8-13 to 9.8-15), the frequency of observed transformations in EEWTP finished waters compared favorably to at least one local supply during all periods tested.

If all tests for the full two year operating period are combined for each site tested, the percent of positive mammalian in EEWTP finished water and local finished waters were as shown below.

EEWTP:	8.3%	(24 assays)
WTP1:	8.7%	(23 assays)
WTP2:	12.0%	(25 assays)
WTP3:	8.3%	(24 assays)

Relative to previously reported assay work on drinking water, the transformation assay results from this project are consistent. Lang, et. al. (1980) used a different mammalian cell line, the BALB/3TC mouse fibroblast, to test drinking water concentrates obtained by reverse osmosis from five U.S. cities. Gruener and Lockwood (1979) used a human diploid cell line to test recycled water concentrates in a soft agar transformation assay. These concentrates were also able to induce in vitro transformation. Kfir (1982) tested unconcentrated samples from the Stander reclamation plant, and Pretoria tap water by the Golden Hamster Cell Transformation Assay. Reclaimed water showed less transforming activity than the conventionally treated potable water. Pelon (1980) observed transformation of R846-DP8 mouse embryo cells in four percent of finished water samples.

In summary, little information is available for interpreting mammalian cell transformation assay results used to predict potential carcinogenicity in complex environmental mixtures, and there is not enough information at this time to extend mammalian cell culture data for purposes of predicting relative health risks in humans. Based on available information and comparison to the current MWA drinking water supply, transformation frequencies observed during the project did not indicate any cause for concern with regard to the health risks associated with EEWTP finished water, based on this toxicological assay.

## SECTION 9

### PLANT RELIABILITY

#### INTRODUCTION

Previous sections of this chapter have addressed the quality of the EEWTP finished water with respect to the various water quality parameter groups. Discussion centered on comparison of EEWTP finished waters with finished waters from the local MWA water treatment plants. A variety of statistical measures were presented, but discussion was centered primarily on the "average" levels of specific parameters in the finished water, as measured by geometric means, arithmetic means, or medians. The EPA drinking water regulations were also considered, with discussion of the potential for EEWTP finished waters to exceed the MCLs.

In this section, an overview of plant process reliability is provided. Process reliability is examined in the context of influent water quality, with influent levels also compared to the drinking water regulations. Consideration is given to both the primary interim drinking water MCLs and the secondary MCLs.

Also considered is the reliability of the EEWTP relative to local water plants in the MWA, as measured by the upper regions of frequency distributions for water quality parameters measured at each site. Considered are the relatively smaller percentages of finished water samples which exhibited parameter concentrations above the mean — specifically, those values which were exceeded by 10 percent or less of the samples (the 90th percentile values). The magnitude of sample concentrations at the upper end of the frequency distribution can be indicative of the reliability of the plant. The concept of reliability is discussed further in the first section below.

#### THE CONCEPT OF RELIABILITY

The concept of reliability, as applied to water treatment plants, can be interpreted as a plant's ability to consistently meet its treatment requirements. For conventional water treatment plants using protected sources, a reliable system might be defined as one which delivers water meeting the federal drinking water standards close to 100 percent of the time. The frequency of sampling will affect the number of samples which are observed to exceed a given level, and can also affect the frequency with which such excesses might be observed. An important implication of the above definition of reliability is that sampling need be no more frequent than required by the regulations.

For treating water from a contaminated source, such as the Potomac Estuary under drought conditions, the concept of reliability is more difficult to define. It is generally agreed that if treated water from a contaminated source is to be



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considered as acceptable for a municipal supply, then it must at least meet the established drinking water standards. In addition, it is advisable to increase the frequency of monitoring, as was done at the EEWTP. Thus, it is of interest to note the percent of analytical results which are in excess of federally established levels, irrespective of the fact that the results were obtained from a monitoring program more exhaustive than required.

When considering the local finished waters, however, it is important to remember that the monitoring requirements specified in the regulations are much less than the monitoring conducted for this project. As an example, any trace metal observed to exceed the standard two percent of the time would most likely be observed once every fifty years with the required annual sampling. Although the local plants monitor much more frequently for purposes of operational control and quality assurance, the annual sample is all that is required for purposes of Federal compliance.

An additional criterion which has been considered in evaluating the EEWTP finished water is that it should compare favorably with the existing supplies in the region. On this basis, water quality parameters have been compared with local supplies to demonstrate, where possible, that the EEWTP finished water had a significantly lower central tendency than the highest local supply, based on statistical definition of significance at the 0.05 level. It is possible, however, that such a significantly lower central tendency could be achieved, despite a small number of values which are well above levels in the local supply. Such high levels may be indicative of a more variable water source and/or less reliable plant operation. Prolonged periods of operation at these higher levels, under conditions of plant upset or inferior influent quality, may be cause for concern. High concentrations in the upper end of the frequency distribution would not necessarily be indicated by the comparisons of geometric means, although the variability of the data (spread factor) does affect the significance of the comparison.

In this context, it is useful to consider the upper ranges of the sample population and compare these among the monitored finished waters. There are several possible ways of comparing the results numerically.

1. Comparison of the percent of samples in excess of some arbitrary level. This is of interest if the selected level has importance (such as an MCL). Such levels have not been established for all parameters of interest, however, and in cases where all values at all sites are below the selected level, the technique is not enlightening.
2. Comparison of the distribution models at high concentration ranges. It is possible to project percentiles at any given level, based on model fits to the log-normal distribution model. Because of the nature of the model, numerical projections are possible at any selected value or percentile, with "percent greater than" becoming very small at very high concentrations. McCarty et. al. (1982) have demonstrated the utility of such estimates of the "predicted percent time" a value is exceeded. The disadvantage of this approach is that it is one step removed from the actual sampling

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data, and can give distorted results if the data are not well fit by the log-normal model.

3. Comparison of the sample concentration at some given arbitrary percentile at the upper end of the frequency distribution.

This latter approach, while arbitrary in nature, has the advantage of allowing numerical comparison of the upper values of sample populations while drawing directly on the analytical results.

For evaluation of the extreme values in EEWTP finished water, the third approach was selected, with 90th percentile values in EEWTP finished water compared to the highest 90th percentile value in one of the monitored waters currently being supplied in the MWA. The 90th percentile was selected because it represents a high concentration (exceeded ten percent of the time), without placing undue weight on analytical "outliers" which could be the result of sample contamination, analytical error, or unusual plant conditions (such as start-up or short test periods).

In some cases, plant conditions were not always fully optimized, such that upper ranges of concentration may not be indicative of what could be achieved had a more extensive start-up and optimization period been feasible. One example of this is pH control, which was not instigated until December 1981 and which influenced trace metal removals during Phase IA. Ammonia control is another example where more extensive provisions for intermediate breakpoint chlorination and final pH control would allow for more consistent operation than that achieved at the EEWTP, during periods of high influent  $\text{NH}_3$  levels.

In general, however, values which were exceeded in ten percent of the samples may be considered as values which might be expected to occur in a full-scale plant under similar influent conditions. It is useful to note how such values compare with similar values in the current MWA supply.

With the above as introduction, the following sections provide data relating to the reliability of EEWTP finished water with respect to:

1. the Federal drinking water MCLs and
2. the upper ranges of concentration in the current MWA supply.

### RELIABILITY MEETING FEDERAL DRINKING WATER REGULATIONS

The process reliability of the EEWTP process combinations can be evaluated by specifying the percent of the time that a given MCL in the primary or secondary drinking water regulations was exceeded during the testing period. The sections below present these data for the three operating periods.

#### PRIMARY DRINKING WATER REGULATIONS

Tables 9.9-1, 9.9-2, and 9.9-3 summarize the EEWTP influent and finished water quality for the three phases of operation, in comparison to the Maximum Contaminant Levels (MCL) as specified in the interim primary drinking water

# Plant Reliability

TABLE 9.9-1  
COMPARISON OF EEWTP WATER QUALITY WITH  
EPA PRIMARY DRINKING WATER MCLs  
PHASE 1A

Parameter	MCL <sup>1</sup>	Influent		Finished Water	
		Geometric Mean	% > MCL	Geometric Mean	% > MCL
Physical/Aesthetic Turbidity	1 NTU	11.07	99.98	0.11	0.05
Major Cations, Anions, Nutrients					
Fluoride <sup>2</sup>	1.6	0.49	0.0	0.30	0.0
Nitrate - N	10	6.90	2.91	6.87	3.51
Trace Metals					
Arsenic	0.05	0.00065	0.0	0.00020	0.0
Barium	1	0.0291	0.0	0.0215	0.0
Cadmium	0.010	0.00010	0.0	NC <sup>3</sup>	0.0
Chromium	0.05	0.00443	9.09	0.00047	0.0
Lead	0.05	0.00158	0.0	0.00033	0.0
Mercury	0.002	0.00009	1.50	0.00020	1.08
Selenium	0.01	0.00039	0.36	0.00051	0.0
Silver	0.05	0.00070	0.0	NC	0.0
Radiological					
Gross Alpha	5 pCi/L	0.25	0.0	0.10	0.0
Gross Beta	50 pCi/L	3.23	0.0	5.93	0.0
Microbiological					
Total Coliforms	1/100 ml	63553.2	93.3	0.0314	0.0
Trihalomethanes					
TTHM	0.1	0.00192	0.0	0.00772	0.0
Trace Organics					
Endrin	0.0002	NC	0.0	NC	0.0
Lindane	0.004	NC	0.0	NC	0.0
Methoxychlor	0.1	NC	0.0	NC	0.0
Toxaphene	0.005	NC	0.0	NC	0.0
2,4-D	0.1	NC	0.0	NC	0.0
2,4,5-TP Silver	0.01	NC	0.0	NC	0.0

1. Units in mg/L unless otherwise noted.

2. Fluoride MCL depends on ambient air temperature. MCL shown is for 21.5 to 26.2 degrees Celsius.

3. NC = Not Calculated. Fewer than fifteen percent of values above MDL.

# Plant Reliability

TABLE 9.9-2  
COMPARISON OF EEWTP WATER QUALITY WITH  
EPA PRIMARY DRINKING WATER MCLs  
PHASE IB

Parameter	MCL <sup>1</sup>	Influent		Finished Water	
		Geometric Mean	% > MCL	Geometric Mean	% > MCL
Physical/Aesthetic					
Turbidity	1 NTU	15.32	100	0.10	0.0
Major Cations, Anions, Nutrients					
Fluoride <sup>2</sup>	1.6	0.44	0.0	0.23	0.0
Nitrate - N	10	6.66	0.0	5.09	0.0
Trace Metals					
Arsenic	0.05	0.00110	0.0	0.00050	0.0
Barium	1	0.0383	0.0	0.0246	0.0
Cadmium	0.01	0.00023	0.0	0.00004	0.0
Chromium	0.05	0.00560	0.0	0.00095	0.0
Lead	0.05	0.00206	3.70	0.00016	0.0
Mercury	0.002	NC <sup>3</sup>	0.0	0.00020	0.0
Selenium	0.01	NC	0.0	0.00006	0.0
Silver	0.05	0.00041	0.0		0.0
Radiological					
Gross Alpha	5 pCi/L	0.37	0.0	0.03	0.0
Gross Beta	50 pCi/L	6.80	0.0	5.02	0.0
Microbiological					
Total Coliforms	1/100 ml	21623.7	92.3	0.0084	0.0
Trihalomethanes					
TTHM	0.1	0.00211	0.0	0.00577	0.0
Trace Organics					
Endrin	0.0002	NC	0.0	NC	0.0
Lindane	0.004	NC	0.0	NC	0.0
Methoxychlor	0.1	NC	0.0	NC	0.0
Toxaphene	0.005	NC	0.0	NC	0.0
2,4-D	0.1	NC	0.0	NC	0.0
2,4,5-TP Silvex	0.01	NC	0.0	NC	0.0

1. Units in mg/L unless otherwise noted.

2. Fluoride MCL depends on ambient air temperature. MCL shown is for 21.5 to 26.2 degrees Celsius.

3. NC = Not Calculated. Fewer than fifteen percent of values above MDL.

# Plant Reliability

TABLE 9.9-3  
COMPARISON OF EEWTP WATER QUALITY WITH  
EPA PRIMARY DRINKING WATER MCLs  
PHASE IIA

Parameter	MCL <sup>1</sup>	Influent		Finished Water	
		Geometric Mean	% > MCL	Geometric Mean	% > MCL
Physical/Aesthetic					
Turbidity	1 NTU	8.72	100	0.06	0.0
Major Cations, Anions, Nutrients					
Fluoride <sup>3</sup>	1.6	0.52	0.0	0.47	0.0
Nitrate - N	10	7.72	3.85	7.71	1.89
Trace Metals					
Arsenic	0.05	0.00058	0.0	0.00037	0.0
Barium	1	0.0303	0.0	0.0166	0.0
Cadmium	0.010	NC <sup>2</sup>	0.0	NC	0.0
Chromium	0.05	0.00407	0.0	0.00123	0.0
Lead	0.05	0.00210	0.0	0.00012	0.0
Mercury	0.002	NC	0.0	0.00009	0.0
Selenium	0.01	0.00028	0.0	0.00046	0.0
Silver	0.05	0.00020	0.0	NC	0.0
Radiological					
Gross Alpha	5.0 pCi/L	NC	0.0	NC	0.0
Gross Beta	50.0 pCi/L	6.25	0.0	5.27	0.0
Microbiological					
Total Coliforms	1/100 ml	28990.0	97.22	NC	0.0
Tribalomethanes					
TTHM	0.1000	0.00244	0.0	0.00125	0.0
Trace Organics					
Endrin	0.0002	NC	0.0	NC	0.0
Lindane	0.004	0.000046	0.0	NC	0.0
Methoxychlor	0.1	NC	0.0	NC	0.0
Toxaphene	0.005	NC	0.0	NC	0.0
2,4-D	0.1	NC	0.0	NC	0.0
2,4,5-TP Silvex	0.01	NC	0.0	NC	0.0

1. Units in mg/L unless otherwise noted.
2. NC = Not Calculated. Fewer than fifteen percent of values above MDL.
3. Fluoride MCL depends on ambient air temperature. MCL shown is for 21.5 to 26.2 degrees Celsius.

## Plant Reliability

regulations. As shown, turbidity and total coliforms were the only water quality parameters that consistently exceeded the MCL in the influent waters. Several other water quality parameters in the blended influent also exceeded their MCLs, but at a significantly lower percent of the time. During Phase IA, influent levels of chromium, mercury, and selenium exceeded the MCL on occasions. During Phase IB, only lead was observed to exceed the MCL, but again infrequently, in only 3.7 percent of the samples. During Phase IIA, no metals exceeded the MCL in the influent waters.

With respect to the major cations, anions and nutrients, only nitrate exceeded the primary MCL, with a low frequency of occurrence, as shown. As discussed previously, however, these events coincided with the use of nitrified effluent as the sole source of EEWTP influent.

As shown in Tables 9.9-1, 9.9-2 and 9.9-3, all three treatment process combinations reliably reduced the turbidity levels below the MCL of 1 NTU. In Phase IA finished water turbidity levels were observed to exceed the MCL on occasions, but infrequently (less than 0.05 percent of the samples).

With respect to total coliforms, the three process combinations were observed to be capable of easily meeting the MCL of 1 MPN/100 ml. No samples exceeded this standard. As discussed previously, however, this MCL may not be stringent enough for evaluating the acceptability for human consumption of water obtained from a contaminated source. The National Research Council Committee on Reuse (NRC, 1982) recommended a goal of 0.1 MPN/100 ml in ninety percent or more of the samples. In comparison to this potential goal, the results show that the EEWTP treatment processes during Phase IA were less reliable than the subsequent treatment process combinations. During Phase IA, approximately 19 percent of the samples exceeded the 0.1 MPN/100 ml goal. The frequency of exceedence dropped to 4.4 percent during Phase IB, and was reduced to zero by the process combination tested in Phase IIA.

Because the treatment processes were not capable of removing nitrate, no discussion of process reliability is relevant for this parameter. It is important to again note, however, that the days during which the nitrate standard was exceeded corresponded to those days when the influent was 100 percent Blue Plains nitrified effluent. Such an event would not occur in the estuary under drought conditions.

With the exception of mercury during Phase IA, the treatment process combinations were quite reliable in reducing trace metal concentrations to below the MCLs. During all three phases, no samples exceeded the MCL, with the exception of mercury. This event occurred during Phase IA and the cause of the higher mercury levels could not be determined.

## SECONDARY REGULATIONS

A comparison of EEWTP water quality in both the influent and finished waters is shown in Tables 9.9-4 to 9.9-6. Geometric mean values and the percent of time that the secondary maximum contaminant levels (SMCLs) were exceeded in both the influent and finished waters are shown.

TABLE 9.9-4  
COMPARISON OF EEWTP WATER QUALITY WITH  
EPA SECONDARY DRINKING WATER MCLs  
PHASE IA

Parameter	SMCL <sup>1,2</sup>	Influent		Finished Water	
		Geometric Mean	% > SMCL	Geometric Mean	% > SMCL
Physical/Aesthetic					
pH <sup>4</sup>	6.5-8.5	7.0	5.73	6.8	31.37
Color	15 CU	33.7	97.51	2.9	0.49
MBAS (Foaming Agents)	0.5	0.063	0.0	0.032	0.0
Odor	3 TON	NA <sup>3</sup>	NA	16.7	99.25
Trace Metals					
Copper	1	0.00609	0.0	0.00249	0.0
Iron	0.3	1.0915	96.69	0.0244	2.52
Manganese	0.05	0.16456	97.08	0.03040	33.81
Zinc	5	0.03070	0.0	0.02183	0.0
Major Cations, Anions, Nutrients					
TDS	500	234.4	0.0	299.4	0.0
Chloride	250	42.43	0.0	46.37	0.0
Sulfate	250	65.76	0.0	91.10	0.0

1. SMCL = Secondary MCL

2. Units are in mg/L unless otherwise specified.

3. NA = Not Analyzed.

4. The >SMCL number includes values exceeding either the upper or lower limit.

TABLE 9.9-5  
COMPARISON OF EEWTP WATER QUALITY WITH  
EPA SECONDARY DRINKING WATER MCLs  
PHASE IB

Parameter	SMCL <sup>1,2</sup>	Influent		Finished Water	
		Geometric Mean	% > SMCL	Geometric Mean	% > SMCL
Physical/Aesthetic					
pH <sup>4</sup>	6.5-8.5	6.9	4.3	7.6	0.22
Color	15 CU	44.9	100	4.9	0.0
MBAS (Foaming Agents)	0.5	0.049	0.0	0.035	0.0
Odor	3 TON	NA <sup>3</sup>	NA	10.4	95.65
Trace Metals					
Copper	1	0.00830	0.0	0.00137	0.0
Iron	0.3	1.5673	100	0.0167	3.13
Manganese	0.05	0.23655	100	0.00456	3.13
Zinc	5	0.02939	0.0	0.00926	0.0
Major Cations, Anions, Nutrients					
TDS	500	207.8	0.0	231.1	0.0
Chloride	250	45.45	0.0	39.68	0.0
Sulfate	250	38.24	0.0	59.52	0.0

1. SMCL = Secondary MCL

2. Units are in mg/L unless otherwise specified.

3. NA = Not Analyzed.

4. The >SMCL number includes values exceeding either the upper or lower limit.



TABLE 9.9-6  
COMPARISON OF LEWTP WATER QUALITY WITH  
EPA SECONDARY DRINKING WATER MCLs  
PHASE IIA

Parameter	SMCL <sup>1,2</sup>	Influent		Finished Water	
		Geometric Mean	% > SMCL	Geometric Mean	% > SMCL
Physical/Aesthetic					
pH <sup>4</sup>	6.5-8.5	7.2	0.0	7.4	0.0
Color	15 CU	47.3	100	10.5	0.0
MBAS (Foaming Agents)	0.5	0.075	0.0	NC <sup>5</sup>	0.0
Odor	3 TON	NA <sup>3</sup>	NA	5.2	56.70
Trace Metals					
Copper	1	0.00707	0.0	0.00096	0.0
Iron	0.3	0.7903	87.27	0.0071	0.0
Manganese	0.05	0.11041	87.27	0.00039	0.0
Zinc	5	0.01540	0.0	0.00830	0.0
Major Cations, Anions, Nutrients					
TDS	500	263.8	0.0	301.5	1.89
Chloride	250	56.05	0.0	60.78	0.0
Sulfate	250	53.69	0.0	54.61	0.0

1. SMCL = Secondary MCL.
2. Units are in mg/L unless otherwise specified.
3. NA = Not Analyzed.
4. The >SMCL number includes values exceeding either the upper or lower limit.
5. NC = Not Calculated. Fewer than fifteen percent of values above the MDL.

Three of the parameters included in the secondary regulations were consistently exceeded in the influent waters during all three phases. These were color, iron, and manganese. The pH also occasionally exceeded the SMCL in the EEWTP influent waters. The primary cause of this was lower pH values in the Blue Plains nitrified effluent.

During all three phases the EEWTP treatment processes effectively reduced the level of blended influent color below the SMCL of 15 color units (CU). No samples were observed to exceed this parameter during Phases IB and IIA. During Phase IA, however, approximately 0.5 percent of the samples exceeded the color standard. These results demonstrate a reliable process combination.

With respect to the two metals exceeding the SMCLs in the blended influent, the process combinations had varying levels of reliability. During Phase IIA, the use of lime for chemical clarification significantly improved the reliability of the process for meeting the SMCLs as shown in Table 9.9-6. The process combination in Phase IA, discussed previously, showed poor reliability in meeting the manganese SMCL. Appropriate control strategies will permit a highly reliable plant operation, however, as has been discussed. In Phase IB, the iron and manganese levels exceeded MCLs in approximately three percent of the samples. The Phase IB processes can be operated more reliably for manganese removal, however, by proper control of the intermediate pH and the ozone dose levels.

### PROCESS RELIABILITY BASED ON NINETY PERCENTILE VALUES

A further indication of process reliability is a comparison of the upper percentiles of the sample population to the MCLs in the primary and secondary regulations, as well as to the highest 90th percentile value observed in one of the three local WTPs. A summary of this information is shown below for each of the three phases of EEWTP operations.

#### PRIMARY REGULATIONS

Table 9.9-7 shows a comparison of the 90th percentile values for the three process operation periods to the MCLs and the highest 90th percentile values observed in the local WTPs. As shown, the 90th percentile values never exceeded an MCL in the primary drinking water regulations. The 90th percentile values for nitrate, gross beta, and total coliforms (in Phase IA and IB) exceeded the highest 90th percentile observed in a local plant, however. In Phase IIA, the 90th percentile total coliform value was less than the highest 90th percentile value observed in one local WTP.

In the case of nitrate and gross beta, the significance of the levels observed has been discussed previously. It is important to note that, while the 90th percentile values were higher, they did not exceed the MCLs. For total coliforms, the Phase IA process combination was not as reliable as the local WTPs during Phase IA. The causes of this were discussed previously. However, closer control of chlorine dose and pH would provide a more reliable process in a full-scale plant with respect to removal of total coliforms.

TABLE 9.9-7  
90TH PERCENTILE VALUES IN EEWTP FINISHED WATER  
RELATIVE TO EPA PRIMARY MCLs

Parameter	MCL <sup>1</sup>	Highest 90% Value of Three Local MWA WTPs	90% Value in EEWTP Finished Water		
			Phase IA	Phase IB	Phase IIA
Physical/Aesthetic					
Turbidity	1 NTU	0.76	0.20	0.15	0.10
Major Cations, Anions, Nutrients					
Fluoride	1.6	1.1	0.4	0.4	0.6
Nitrate-N	10	2.5	9.33	8.0	9.6
Trace Metals					
Arsenic	0.05	0.0011	0.0009	0.0010	0.0009
Barium	1	0.047	0.032	0.031	0.024
Cadmium	0.10	ND <sup>2</sup>	ND	0.0006	ND
Chromium	0.05	0.0052	0.0024	0.0025	0.0038
Lead	0.05	0.0016	0.0016	0.0006	0.0007
Mercury	0.002	0.0016	0.0007	0.0005	0.0004
Selenium	0.01	0.0027	0.0026	0.0004	0.0015
Silver	0.05	0.0003	ND	ND	ND
Radiological					
Gross Alpha	5 pCi/L	0.8	0.6	0.9	ND
Gross Beta	50 pCi/L	5.8	12.0	5.9	7.6
Microbiological					
Total Coliforms	1/100 ml	0.23	0.49	0.23	ND
Trihalomethane					
TTHM	0.1	0.1029	0.0251	0.0140	0.0043
Trace Organics					
Endrin	0.0002	ND	ND	ND	ND
Lindane	0.004	ND	ND	ND	ND
Methoxychlor	0.1	ND	ND	ND	ND
Methoxychlor	0.1	ND	ND	ND	ND
Toxaphene	0.005	ND	ND	ND	ND
2,4-D	0.1	ND	ND	ND	ND
2,4,5-TP Silvex	0.01	ND	ND	ND	ND

1. Units in mg/L unless otherwise noted.

2. ND = Not Detected.

3. Values in bold exceed highest 90% value in local WTPs.

## SECONDARY REGULATIONS

Table 9.9-8 shows the 90th highest percentile values in the EEWTP finished waters relative to the SMCLs and the highest 90th percentile value observed in the local WTPs. In comparing the 90th percentile values in the EEWTP finished waters with the SMCLs, both pH, odor, and manganese values exceeded the MCLs in one or more phases. Both pH and manganese reliability issues can be resolved using appropriate process operational strategies as discussed previously. As discussed, the high odor levels have been attributed to a highly sensitive odor panel.

The 90th percentile values for TDS, chloride, and sulfate (Phase IA only) exceeded the highest 90th percentile values observed in the three local WTPs. Manganese and zinc levels in Phases IA and IB also exceeded the highest 90th percentile value observed in the local plants for Phase IA. Proper attention to pH control and the use of an intermediate oxidant should control the manganese levels within acceptable limits. Zinc levels, which exceeded the highest value observed in the local WTPs, would not cause any aesthetic problems. The levels observed were considerably lower than the SMCL of 5 mg/L.

The odor results show that 90th percentile values observed in Phase IA and IIA exceeded the highest 90th percentile values observed in the three local WTPs. It is expected that under actual full-scale operating conditions, however, these occasional high odor values would be controlled by closer control of chlorine dose. The Phase IIA arithmetic and geometric mean odor values were lower than those observed during Phase IA and IB, and also lower than the local WTPs.

## OTHER PARAMETERS OF POTENTIAL HEALTH OR AESTHETIC CONCERN

Tables 9.9-9 and 9.9-10 compare the 90th percentile values of the EEWTP finished waters to the highest 90th percentile observed in the three local WTPs. The water quality parameters included are those parameters considered to be of health or aesthetic concern, but which are currently not included in the primary or secondary regulations.

As shown in Table 9.9-9, the reliability of the EEWTP process compares favorably with that observed in the local WTPs. Although some 90th percentiles exceeded the highest value observed in the local WTPs, the values observed would not cause any undue health or aesthetic problems in the finished water. The parameters which exceeded local 90th percentile values were hardness, sodium, ammonia, antimony, nickel and tin. As discussed previously, the levels observed are not of health or aesthetic concern, with the exception of sodium. The sodium levels depended only on the influent levels, because the EEWTP process combinations were not capable of removing sodium.

With respect to microbiological contaminants, EEWTP fecal coliform levels exceeded the highest 90th percentile value observed in the local WTPs during Phase IA. This result was due to the operating strategies tested during Phase IA. Appropriate control of the finished water chlorine dose would provide increased reliability for the Phase IA process configuration.

TABLE 9.9-8  
90TH PERCENTILE VALUES IN EEWTP FINISHED WATER  
RELATIVE TO EPA SECONDARY MCLs

Parameter	SMCL <sup>1,2</sup>	Highest 90% Value of Three Local MWA WTPs	90% Value in EEWTP Finished Water		
			Phase IA	Phase IB	Phase IIA
Physical/Aesthetic					
pH	6.5-8.5	9.2	9.2	8.8	7.8
90% Value		7.3	6.33	7.3	7.2
10% Value		15	7	7	15
Color	15 CU	0.06	0.05	0.04	0.03
MBAS (Foaming Agents)	0.5	25	50	17	40
Odor	3 TON				
Trace Metals					
Copper	1	0.0081	0.0094	0.0024	0.0031
Iron	0.3	0.1400	0.0840	0.0560	0.0360
Manganese	0.05	0.0200	0.1093	0.0203	0.0081
Zinc	5	0.0160	0.0646	0.0286	0.0180
Major Cations, Anions, Nutrients					
TDS	500	238	353	268	347
Chloride	250	47	60.5	54	68.0
Sulfate	250	82.0	118.9	69.0	71.0

1. SMCL = Secondary MCL.

2. Units in mg/L unless otherwise noted.

3. Values in bold exceeded highest 90% value in local WTPs.

# Plant Reliability

TABLE 9.9-9  
90th PERCENTILE VALUES IN EEWTP FINISHED WATER RELATIVE TO  
LOCAL MWA FINISHED WATERS FOR ADDITIONAL PARAMETERS  
OF HEALTH OR AESTHETIC CONCERN

Parameter <sup>1</sup>	Highest 90% Value of Three Local MWA WTPs	90% Value in EEWTP Finished Water	
		Phase IA	Phase IB
Physical/Aesthetic			
Cryptite Asbestos Fibers (MFL) <sup>3</sup>	0.41	ND <sup>2</sup>	ND
Amphibole Asbestos Fibers (MFL)	ND	ND	ND
Major Cations, Anions, Nutrients			
Ammonia (N)	0.76	0.06	0.07
Hardness	174	199	174
Bromide	0.020	0.035	0.014
Cyanide	0.009	0.011	ND
Sodium	22.6	37.4	28.2
Trace Metals			
Antimony	0.0006	0.0010	NA
Beryllium	ND	ND	NA
Nickel	0.0061	0.0058	0.0084
Thallium	ND	ND	NA
Tin	0.0074	0.0076	NA
Microbiological			
Fecal Coliforms (per 100 ml)	0.02	0.06	0.02
SPC (colonies/ml)	340	300	29
Surrogate Organics			
TOC	4.7	2.2	1.8
TOX (µg/L)	410	195	60
			1.2 75

1. Units in mg/L unless otherwise noted.

2. ND = Not Detected.

3. MFL = Million Fibers per Liter.

4. Values in bold exceeded highest 90% value in local WTPs.

TABLE 9.9-10  
90th PERCENTILE VALUES IN EEWTP FINISHED WATERS RELATIVE  
TO LOCAL MWA FINISHED WATER FOR VOLATILE ORGANIC CHEMICALS  
BEING CONSIDERED FOR REGULATION

Parameter <sup>a</sup>	Highest 90% Value of Three Local MWA WTPs	90% Value in EEWTP Finished Water		
		Phase IA	Phase IB	Phase IIA
Carbon Tetrachloride (LLE) <sup>b</sup>	0.3	<0.2 <sup>c</sup>	<0.1	<0.1
Trichloroethene (LLE)	<0.3	<0.3	<0.1	<0.1
Tetrachloroethene (LLE)	<0.4	<0.4	<0.4	<0.1
Tetrachloroethene (CLS)	0.12	<b>0.23<sup>d</sup></b>	<b>0.16</b>	<b>0.17</b>
1,2 Dichloroethane (PT)	<0.1	<0.1	<0.1	<0.1
Vinyl Chloride (PT)	<0.1	<0.1	<0.1	<0.1
1,1,1 Trichloroethane (PT)	0.3	<0.2	<0.1	<0.2

a. Units in  $\mu\text{g/L}$ .

b. LLE = Liquid/Liquid Extraction; CLS = Closed Loop Stripping; PT = Purge and Trap.

c. Numbers shown as less than (<) are the method detection limit or the instrument detection limit.

d. Values in bold exceeded highest 90% value in local WTPs.

## Plant Reliability

Table 9.9-10 compares the 90th percentile values in the EEWTP finished waters with the highest 90th percentile value observed in the local WTPs for six volatile organic chemicals (VOCs) being considered for regulation by EPA. As expected, based on the previous discussion of organics results, the 90th percentile value observed in the EEWTP finished waters were generally comparable to or lower than those observed in the local WTPs. The only exception to this was tetrachloroethene (or PCE) as determined by the closed-loop stripping technique. The 90th percentile values in all three phases exceeded the highest 90th percentile value observed in a local WTP. The values, however, are considerably below the concentrations anticipated to produce chronic health risks to the consumer. As discussed previously, the one in a million ( $10^{-6}$ ) risk level for PCE is estimated to be 3.5  $\mu\text{g/L}$ .

### SUMMARY

For all water quality parameters included in the primary and secondary drinking water regulations, as well as those additional water quality parameters considered to be of potential health or aesthetic concern in the finished waters, the EEWTP process combinations generally performed reliably during the test period. The EEWTP process combinations were demonstrated to perform reliably in meeting all of the MCLs in more than 95 percent of the samples. Those exceptions, in particular, manganese and odor and total coliforms, can be controlled by the use of proper operational parameters.



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## CHAPTER 10

### SPECIAL TESTING AND EVALUATION

Previous chapters of this report have dealt extensively with the overall evaluation of results obtained during the two year operation of the EEWTP, including influent quality, process performance, and evaluation of finished water quality. Results presented have consisted primarily of analytical and operational data from routine plant monitoring.

In addition to routine monitoring and evaluation of the plant performance, a number of special studies were conducted to further characterize and optimize the plant processes, as well as to investigate other potential processes not examined at the demonstration plant level. These studies were part of a Testing Program for Process Adjustment and Modifications (TPPAM) conducted during the course of the project.

Section I of this chapter provides an overview of the study objectives and findings. Each of the various studies is further discussed in Section 2 (Process Characterization) or Section 3 (Investigations of Alternative Process Designs). In these sections, summaries are provided of the background, approach, results, and recommendations of each individual study. Detailed information for the work, including methods and more detailed results, may be found in Appendix I.

## SECTION 1

### OVERVIEW, SUMMARY, AND RECOMMENDATIONS

#### OBJECTIVES

The special studies conducted over the course of this project had two primary objectives:

1. Process characterization and optimization
2. Investigation of alternative process designs

#### PROCESS CHARACTERIZATION AND OPTIMIZATION

A number of studies were designed to provide additional information about the plant-scale processes, beyond what was available from the routine plant monitoring. In some cases, these studies were designed to further evaluate and optimize the process. Areas of special study were generally those for which information was limited or for which available information could not be extrapolated to the specific process problems encountered in this project without specific testing. Individual study areas and their major objectives are reviewed in Table 10.1-1.

#### INVESTIGATION OF ALTERNATIVE PROCESS DESIGNS

In addition to the characterization and optimization of EEWTP processes, other investigations were conducted to evaluate alternative processes (or alternative designs for existing processes) which could potentially offer significant water quality improvements and/or cost savings. Studies were conducted to evaluate, at a preliminary pilot level, the type of performance which might be expected from the process and, where feasible, to optimize the design criteria. The major objectives of the studies and the individual process alternatives studied are indicated in Table 10.1-2.

### SUMMARY AND RECOMMENDATIONS

#### PROCESS CHARACTERIZATION AND OPTIMIZATION

The results and major findings from each of the seven studies listed in Table 10.1-1 are briefly discussed in the sections below.

##### Coagulation Bench Testing

Alum Coagulation. Bench testing with aluminum sulfate (alum) alone and in combination with a variety of polymeric coagulant aids indicated that an alum dose of between 40 to 60 mg/L- $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$  should be anticipated for effectively treating an influent water of the quality observed at the EEWTP.



TABLE 10.1-1  
SPECIAL STUDIES FOR PROCESS CHARACTERIZATION  
AND OPTIMIZATION

<u>Special Study</u>	<u>Major Objective(s)</u>
Coagulation Bench Testing	Evaluation and optimization of alternative chemical combinations for TOC and turbidity removal.
Filtration Testing	Evaluation of filtration rate and filter aid selection.
GAC Special Study	Qualitative evaluation of synthetic organic chemicals adsorbed on plant GAC, including compounds at undetectable levels in source waters.
Manganese Removal Study	Characterization of EEWTP processes with respect to iron and manganese removal; evaluation of alternative methods of removal.
THM/TOX Formation Study	Evaluation of THM/TOX formation potential in EEWTP process waters as well as EEWTP and local MWA finished waters.
Corrosion Study	Evaluation of the corrosivity of the EEWTP finished water under different operating conditions as encountered over the course of the study.
Hydraulic Characterization	Evaluation of the hydraulic characteristics of fundamental unit processes employed at the EEWTP, in order to locate potential problem areas and to aid evaluation of process performance.

## Overview, Summary, and Recommendations

TABLE 10.1-2  
SPECIAL INVESTIGATIONS OF ALTERNATIVE PROCESS DESIGNS

Process	Major Objective(s)
Granular Activated Carbon Adsorption	<ul style="list-style-type: none"><li>- Modeling of the GAC adsorption process for three carbons including determination of appropriate isotherm and rate model parameters for TOC and one SOC (PCE).</li><li>- Evaluation of GAC design alternatives at different finished water treatment objectives for TOC, and optimization of design criteria with respect to empty bed contact time.</li><li>- Modeling of alternative design scenarios and estimation of costs.</li></ul>
Packed Tower Aeration	<ul style="list-style-type: none"><li>- Evaluation of mass transfer coefficients in EEWTP filtered water for selected SOCs with a selected tower packing.</li><li>- Evaluation and optimization of alternative designs for a selected influent scenario and estimation of costs.</li></ul>
Reverse Osmosis	<ul style="list-style-type: none"><li>- Evaluation of the performance of a polyamide hollow fiber reverse osmosis process with respect to selected inorganic and organic parameters; estimation of costs.</li></ul>

## Overview, Summary, and Recommendations

Addition of a high molecular weight polyelectrolyte, of anionic, cationic, or nonionic charge, is recommended to aid in the settling of floc solids, although no benefits with respect to removal of dissolved TOC could be demonstrated. TOC removals on the order of 30 to 35 percent were the highest that could be achieved with cost effective alum doses, and were similar to removals achieved at plant scale. Alum doses up to 240 mg/L were evaluated for removal of TOC. TOC removals never exceeded forty percent, indicating the difficulties in coagulating and settling the naturally occurring organics in the EEWTP influent. As anticipated from other studies, the optimum pH for TOC removal with alum was in the range of 6.5 to 7.0

Lime Coagulation. Bench testing of lime and lime/coagulant aid combinations indicated that ferric chloride ( $\text{FeCl}_3$ ) was most effective in reducing the lime dose required for effective settling of turbidity and TOC. Comparable performance could not be achieved with lime and selected polymers. Successful operation was demonstrated at process pH levels of 10.5 to 11 and with a ferric chloride dose of 2 mg/L. This operation had an associated lime dose of between 70 and 80 mg/L-CaO, dependent upon influent alkalinity. Turbidity removals of between 80 and 95 percent were achieved during plant scale operation at these doses. TOC removal of up to 45 percent was achieved during bench testing with lime, but only at very high lime doses (over 200 mg/L-CaO). Lime clarification demonstrated the additional advantage of microbiological kill, with greater than 99 percent kill (2.5 log kill) observed at plant scale; see Chapter 8.

Lime coagulation without ferric chloride as a coagulant aid was demonstrated to be impractical due to high lime requirements and resulting concerns over sludge volumes and finished water hardness. The addition of soda ash ( $\text{Na}_2\text{CO}_3$ ) for alkalinity adjustment was evaluated as a means of reducing the finished water calcium levels. Soda ash addition led to increasing lime requirements, however, and was removed from further consideration.

### Filtration Studies

A limited series of pilot filter columns were operated on alum coagulated waters to evaluate the effects of surface loading rates (3, 6 and 9 gpm/ft<sup>2</sup>) and polymers as filter aids. The pilot results suggested that a filtration rate of 6 gpm/ft<sup>2</sup> could achieve similar effluent quality as 3 gpm/ft<sup>2</sup> with respect to turbidity and TOC with only slight reductions in filter water production. Poor results were observed at 9 gpm/ft<sup>2</sup>, with rapid breakthrough occurring. Plant scale experience at 6 gpm/ft<sup>2</sup> was conducted only for relatively short periods of time and with ambiguous results during Phase IA (see Chapter 7). The results indicate that an effective filter aid may be required before good performance can be assured at loading rates above 3 gpm/ft<sup>2</sup>. Observed improvements in plant scale performance when using ozonation before filtration, as discussed in Chapter 7, do suggest that higher loading rates may be feasible without polymers under this configuration. Similarly, plant scale performance with lime coagulation also suggested that higher loading rates may be feasible without polymer addition. Limited pilot testing with selected cationic polymers failed to demonstrate any benefit with respect to TOC removal.

## Overview, Summary, and Recommendations

Based on these results, preliminary full-scale design in the alum/polymer mode should be based on the lower filtration rate operated at the EEWTP. Higher loading rates show promise, however, and warrant further consideration prior to design and construction of an estuary water treatment plant.

### Special GAC Study

A qualitative study of the organic compounds accumulated on the GAC during Phase IA was conducted. Samples of GAC were taken from the columns after approximately 15,000 bed volumes had been treated by GAC. Samples were sent to an outside laboratory for extraction and analyzing by GC/MS using high resolution techniques.

The results revealed twenty-six synthetic organic chemicals which had been effectively removed to some degree and could be subsequently extracted and detected by the techniques utilized. Ten chemicals were identified which had not been previously detected through influent plant monitoring. These compounds were most likely present in concentrations below analytical detection limits, although it is possible that spikes may have entered the plant and escaped sampling. In any event, it is unlikely that chronic doses of any of the additional detected compounds were sufficiently high to be of health concern, and the results of the study did not alter the evaluation of EEWTP finished water quality, as discussed in Chapter 9.

### Manganese Removal Studies

High influent manganese levels were not effectively reduced to levels below the Secondary Maximum Contaminant Level (SMCL) of 0.05 mg/L by the Phase I (alum coagulation) process, without special control measures. Speciation tests indicated that influent manganese in soluble forms was present in significant quantities in both source waters. Bench testing and plant scale evaluations revealed that effective removal could be achieved through the proper combination of oxidant additions and pH control. Satisfactory control of manganese was achieved by three strategies:

1. Addition of permanganate to blended influent with lime addition to raise pH to 7.5 or above following sedimentation.
2. Intermediate ozonation with similar pH adjustment.
3. Lime coagulation (with pH above 10.5 during sedimentation).

It should be noted that chlorination immediately prior to filtration did not adequately remove Mn with or without pH adjustment. Permanganate addition without pH control before filtration was only modestly beneficial. Ozonation prior to filtration but without prior pH control was not tested.

### THM/TOX Formation Studies

Based on the results of total trihalomethane (TTHM) formation studies at 1,4, and 7 days of free chlorine contact, the EEWTP finished water during all phases

of operation compared favorably to local MWA finished waters. Moreover, results suggest that chlorination of gravity filtered water from Phase I or Phase II would also compare favorably, assuming chlorination conditions similar to those practiced on EEWTP finished water (2 to 3 mg/L free chlorine after sixty minutes of contact). GAC is thus not required to meet federal standards for THMs; its recommended use, and associated regeneration criteria, should be based on other SOC's of concern, including other chlorination by-products or potential influent contaminants.

The THM formation studies showed yields of 4-day TTHM, in terms of  $\mu\text{g-Cl}$  of TTHM per mg-C of TOC, to vary between 18  $\mu\text{g/mg}$  and 44  $\mu\text{g/mg}$ , depending on water source, pH, and chlorination conditions. For most waters tested, the 4-day yield was on the order to 35 to 44  $\mu\text{g/mg}$  at pH levels of 7.5 to 7.7.

Kinetic tests revealed that both TOX and TTHM formation increased with chlorine dose, as anticipated. With respect to pH, maximum formation rates for TTHM and TOX were observed at 11.0 and 7.5, respectively, with 11.0 being the highest pH tested. Thus, lower finished water pH may reduce the quantity of THMs during chlorination, but TOX levels will not be diminished until the pH drops to 7 or less. This latter is not recommended due to corrosivity concerns, as discussed below.

#### Corrosion Testing

Corrosion weight loss and penetration tests with metallic inserts indicated an apparent increase in corrosivity during Phase II for seven of nine inserts tested in each phase, despite the fact that all measured corrosion indices (including buffer intensity, Langelier index and Larson's ratio) would suggest lower rates of corrosion compared to Phase I. Inserts were subjected to finished water for two, three and five month durations. Test results with galvanized steel and copper revealed relatively little corrosion, with results not significantly different between the two phases. For these two metals, corrosion rates were higher during the lime phase, at all durations for the inserts. Corrosivity in black iron for the five month lime phase inserts was corroborated by visual observation of pitting on the insert. These results are not well understood, but it is suspected that residual ozone or ozone by-products may be attacking the metals even after two hours of detention since ozonation. Black iron piping is, therefore, not recommended for any full scale plant piping after an ozonation process. In light of the measured buffer intensity, Langelier index and Larson's ratio associated with this water, however, it is highly unlikely that similar corrosivity would be observed in the more remote piping of a distribution system.

#### Hydraulic Characterization

Tracer studies using lithium indicated that most EEWTP processes had hydraulic characteristics very similar to design intentions. All mixing basins behaved essentially as completely mixed reactors. Short circuiting was observed in the sedimentation basin, however, where the peak of the tracer curve exited the basin in one quarter of the theoretical detention time. However, the basin was of sufficiently conservative design that the detention time of the peak was over one hour, and fifty percent of influent water remained in the basin approxi-

mately three hours. It is estimated that a full-scale plant with proper baffling could be operated at twice the loading rate with no loss in process efficiency. Such design is recommended, as discussed in Chapter 11.

Hydraulic testing of the chlorine contact basin indicated reasonably good plug flow characteristics, with a longitudinal dispersion number of 0.086. Perfect plug flow would give a dispersion number of zero. Assuming first order disinfection kinetics and 99 percent kill, this is comparable to a perfect plug flow detention time of about 43 minutes compared to the theoretical hydraulic detention time of 56 minutes. Higher assumed removal rates are associated with slightly lower equivalent detention times.

#### INVESTIGATIONS OF ALTERNATIVE PROCESS DESIGNS

The results and major findings from the studies of alternative GAC design, packed tower aeration, and reverse osmosis are briefly summarized in the sections below.

##### GAC Adsorption

Extensive bench-scale and pilot-scale work was undertaken in order to model the GAC process for adsorption of TOC. Adsorption models were developed for TOC adsorption onto three different carbons and with both alum/polymer and lime pre-treated water. Adsorption of TOC onto F-400 bituminous based carbon was evaluated at plant-scale and it was therefore possible to verify the model prediction for this case with plant scale results. The verification was successful, model predictions closely followed the observed GAC effluent data.

Based on the bench-scale work, the bituminous based carbons showed the most promise for cost effective full-scale operation, with Calgon F-400 exhibiting the highest estimated TOC adsorption capacity of the three carbons tested. This carbon was utilized for subsequent model runs to evaluate alternative design criteria and treatment objectives for full-scale operation. Capital costs were estimated based upon assumed contactor configurations, as determined from literature evaluation and practical constraints. Regeneration costs were determined from model generated carbon usage rates in combination with preliminary assumptions regarding regeneration facility design.

Major findings are summarized below:

1. If carbon regeneration were to be based on effluent TOC criteria from a single GAC contactor (as opposed to many contactors operating in parallel), usage rates would be reduced at longer empty bed contact times (EBCT), and significantly so for TOC treatment objectives of 1.5 mg/L or less. The lowest usage rate was estimated for columns of the longest EBCT tested, sixty minutes.
2. Full-scale design will necessarily have a large number of contactors in parallel, due to practical constraints associated with loading rate and contactor size. Similarly, regeneration will, of necessity, be staged such that the blended effluent will be at a steady state level of TOC. In this

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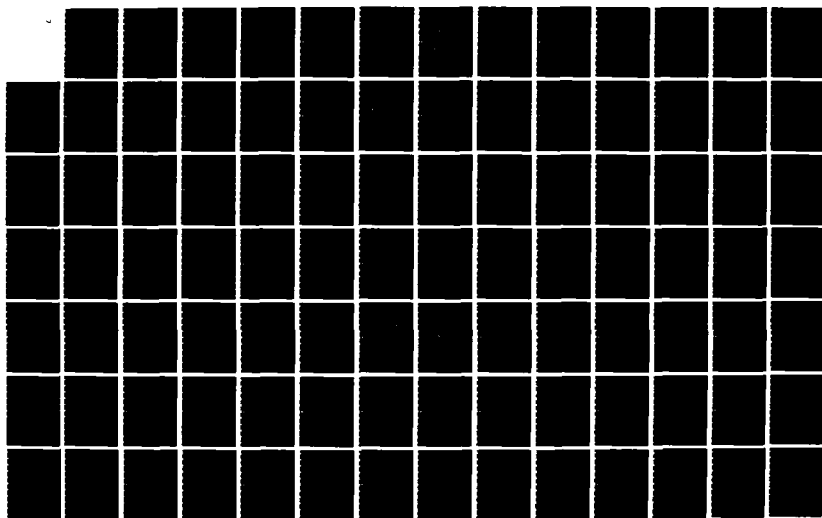
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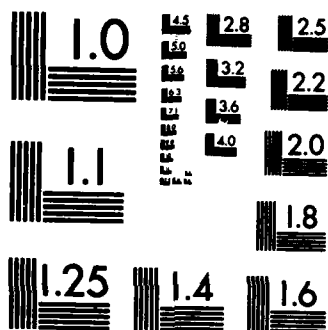
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## Overview, Summary, and Recommendations

case, carbon usage rates are significantly reduced if regeneration is based on criteria for the blended effluent rather than for the effluent from individual columns, with reduction of between fifty and sixty percent indicated from the results of this study.

3. If the regeneration criterion is based on the blended effluent from parallel columns, longer EBCTs will not significantly reduce the carbon usage for TOC removal, except at extremely stringent TOC goals (less than 1 mg/L). The higher capital costs associated with longer EBCTs make them not cost effective. EBCTs of less than fifteen minutes would be recommended to meet TOC criteria of 1.0 mg/L or more. However, low EBCTs were never operated at EEWTP plant-scale and their effectiveness as a barrier to SOC's was not demonstrated.
4. Pilot-scale spiking with tetrachloroethene (PCE) at very high levels for a five day duration failed to produce breakthrough in the pilot columns. Moreover, the concentrations of other less adsorbable SOC's did not increase in the column effluent, suggesting that any SOC's which were displaced by the PCE were effectively re-adsorbed in lower portions of the column. This result indicated that the carbon functioned as an effective barrier for SOC's under these conditions. It should be noted that the spiking study was conducted after over 17,000 bed volumes of EEWTP gravity filter effluent had been fed to the column. TOC removal at this point had essentially reached a steady state, at a removal of approximately twenty percent.
5. On the basis of the results of this study, a fifteen minute EBCT is recommended for full-scale application, with two-stage series operation for added protection against SOC breakthrough. For a 200 MGD full-scale plant, 32 parallel sets of gravity contactors are recommended, each with a loading rate of 5 gpm/ft<sup>2</sup> and an individual contactor surface area of 900 square feet.
6. Selection of the target TOC effluent criterion for carbon regeneration is difficult, because TOC levels do not correlate with potential health effects to consumers. Selection of a lower TOC value is more conservative and provides a greater degree of protection to consumers, but at an increase in cost. Costs for several TOC treatment objectives were generated for this study and are presented in Section 3.
7. Because of the contaminated source, it is recommended that a regeneration criterion of 1 mg/L TOC (the lowest criterion evaluated) be assumed when considering the blended effluent from many columns operated in parallel. GAC operating costs with this criterion are still lower than those generated on the basis of the EEWTP single column experience, as discussed in Chapter 11.

### Packed Tower Aeration

Evaluation of packed tower aeration at pilot-scale produced mass transfer coefficients as a function of liquid loading rate for four relatively volatile SOC's

## Overview, Summary, and Recommendations

(chloroform, trichloroethylene, tetrachloroethylene, and carbon tetrachloride) in the EEWTP source water and for a selected plastic packing media. These results were used to develop optimum design and cost information for a selected arbitrary removal requirement.

Using the information developed in this study, alternative designs may be readily evaluated for other selected volatile contaminants, given reasonably accurate information on the equilibrium properties (Henry's constant) of the compounds and their molecular diffusivity. For chemicals less volatile than chloroform, the mass transfer correlation assumed for this project may not be valid, due to influences of gas phase transfer resistance. One such less volatile compound, bromoform, was evaluated with the pilot packed tower, and removal information for the specific tower conditions was obtained.

It is recommended that air stripping be considered as a potential barrier to be used in conjunction with GAC. In the event of high influent levels of volatile SOCs, a counter current packed tower could provide additional protection beyond that offered by the GAC alone, and could offer substantial savings in terms of carbon regeneration costs.

In the absence of any additional information regarding the nature and concentration of potential organic contaminants in the Potomac estuary, a conservative design has been recommended which would assure greater than ninety percent removal of chloroform under the coldest anticipated water quality conditions (4°C). Removals of chloroform, and PCE, TCE, and CCl<sub>4</sub>, three VOCs considered for regulation by EPA, would all be in excess of 96 percent at water temperatures of 20°C and above. This design is recommended for consideration. Assumed cost should be based on capital cost alone, with an assumption that the unit would only be operated during periods when associated savings in carbon regeneration would more than off-set the operational costs of air stripping. Capital and operating costs of the proposed design have been determined for purposes of reference and are presented in Section 3 of this chapter.

### Reverse Osmosis

Sidestream testing of the reverse osmosis (RO) process was conducted using a 7 gpm sidestream of filtered water. The RO process utilized spiral-wound hollow fiber (Dupont Permasep) membranes operated at 350 psig. The testing program indicated that significant removals of most inorganic parameters could be achieved with removals of nitrate, sodium, and total dissolved solids all demonstrated to be in excess of ninety percent. Negligible ammonia removals were observed, however. TOC removals of eighty percent were observed with an effluent TOC of approximately 0.6 mg/L-C. The TOX concentration was reduced to a level below the detection limit of 3.9 µg/L-Cl. There was some indication that smaller SOC molecules, such as the THMs, were not as effectively removed. Total THM removals of fifty percent were achieved.

If removal of nitrate, sodium or TDS should be required for the full-scale estuary plant, as discussed in Chapter 11, Section 7, RO is a viable alternative for consideration and has been demonstrated to be effective. If utilized, it

## Overview, Summary, and Recommendations

could only be recommended for use on a split portion of the total flow, due to excessive costs. For example, application of RO to produce 100 MGD of treated water is estimated to require the processing of 118 MGD at 85 percent efficiency with costs on the order of 50.3 cents per 1,000 gallons of finished water. In addition, significant problems of brine disposal should be anticipated.

The reverse osmosis process would only be recommended if problems with nitrate, sodium or TDS are higher than currently projected for the estuary under drought conditions (see Chapter 6). As discussed in Chapter 9, the plant-scale processes produced generally acceptable water with respect to these parameters except when influent conditions were worse than those expected for the estuary under the projected drought conditions. Although RO was demonstrated to be effective for the removal of organics, and particularly with respect to TOX, the process is not cost effective relative to GAC and is not recommended for organics removal alone.

## SECTION 2

### PROCESS CHARACTERIZATION AND OPTIMIZATION

#### INTRODUCTION

The studies described in this section were conducted as part of a continuing effort to characterize and optimize the treatment processes employed at the EEWTP. The aim of each of these studies was to develop information for the adjustment of process variables, with fundamental design criteria unchanged from that established at the EEWTP.

#### COAGULATION

##### BACKGROUND AND APPROACH

Historically, destabilization of influent particulate matter in the form of turbidity has been recognized as the primary purpose of the coagulation process. Recently, attention has been focused on the control of trihalomethanes, suspected cancer causing compounds. Humic substances, measured in terms of total organic carbon (TOC), are prevalent in the EEWTP influent and are precursors to the formation of trihalomethanes and other chlorinated organics. These substances can be removed during coagulation; however, operating conditions must be selected which are also effective in the removal of turbidity. Therefore, the coagulation chemistry at the EEWTP was evaluated with the objective of determining optimum conditions for removal of both TOC and turbidity.

By optimizing the coagulation process, maximum removals of turbidity, TOC, metals, bacteria and asbestos can be achieved for minimum coagulant costs. In addition, increased removal of humic material during coagulation will result in a more effective utilization of the granular activated carbon and reduced formation of disinfection by-products, such as chlorinated organics. Finally, cost of the chemicals for coagulation can be decreased by selection of appropriate conditions for coagulation, including pH, coagulant type, coagulant/polymer combination, and dose.

To evaluate the coagulation process under controlled conditions, bench-scale jar tests were performed, and the results applied to full-scale operation for verification.

For alum coagulation, separate sets of jar tests were conducted to evaluate alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ ) as a primary coagulant, with and without one of a variety of potential polymeric coagulant aids, and over a range of pH values. Twenty-four different coagulant aids were considered, of which fourteen were tested at the bench level. These polymers were representative of the polymers currently approved by EPA for use in water treatment and thought to be capable of improving turbidity and TOC removal.

## Process Characterization and Optimization

For lime coagulation, jar tests were conducted to evaluate 1) the effects of variations in lime dose and 2) the effectiveness of coagulant aids for improving removal of turbidity and TOC. Chemicals examined included several anionic and cationic polymers, and ferric chloride ( $\text{FeCl}_3$ ). In addition, chemical conditions were evaluated by variation of alkalinity using soda ash ( $\text{Na}_2\text{CO}_3$ ).

For both alum and lime coagulation, the primary coagulant was tested separately with each of the influent sources to the EEWTP in an effort to determine the removal characteristics of humic compounds present in the two source waters. Detailed information relating to the actual series of jar tests which were conducted is provided in Appendix I, Section 1.

### DISCUSSION OF RESULTS

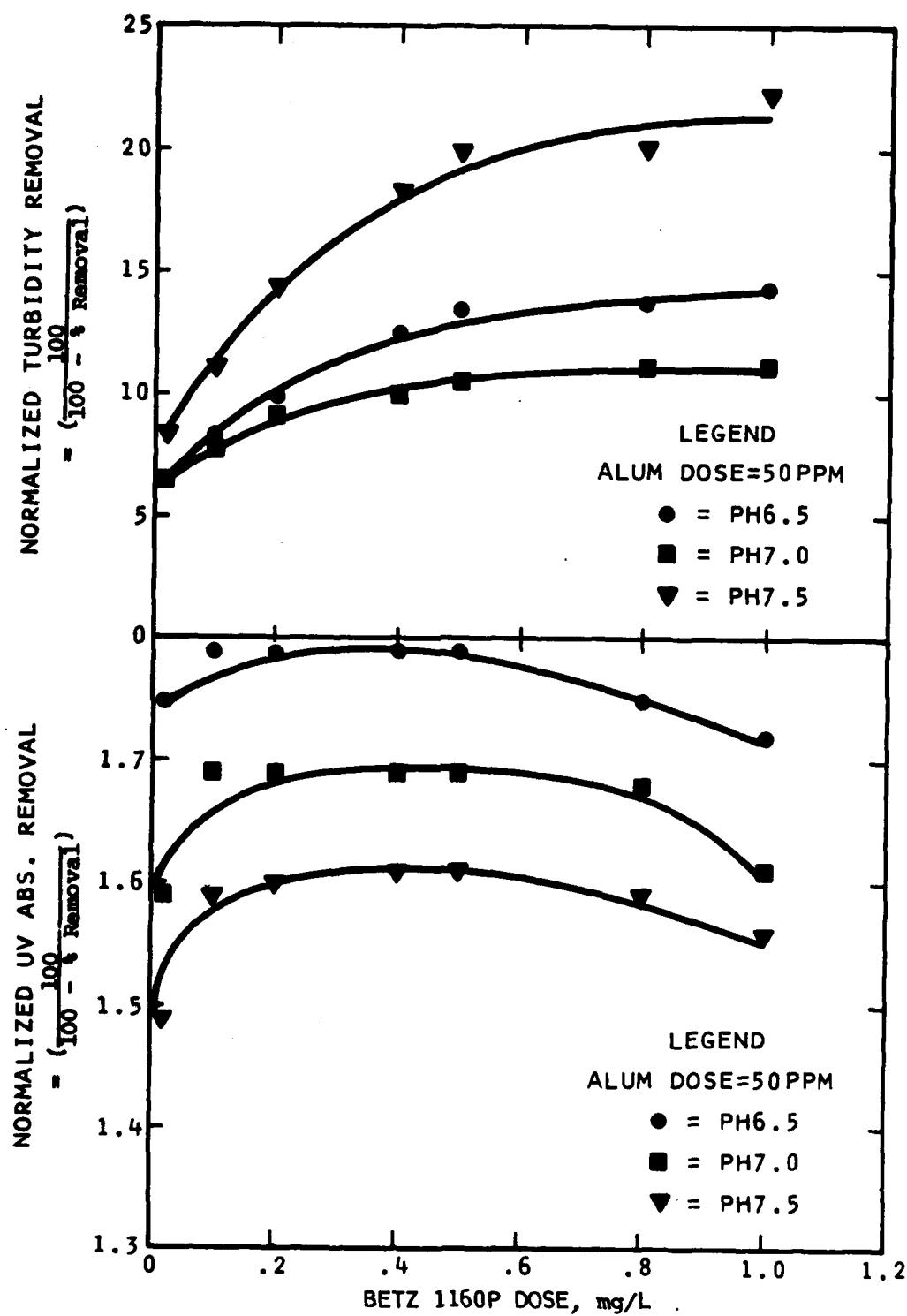
#### Alum Coagulation

Under the laboratory conditions associated with operational jar testing, the optimum alum dose, for alum alone, was generally in the region of 40 to 60 mg/L as alum. Turbidity removals on the order of 90 to 95 percent could be achieved with TOC removal on the order of thirty to forty percent. Plant-scale experience indicated a similar range of optimum alum doses. However, consistently good plant-scale turbidity removal through sedimentation and filtration could not be achieved without the use of a polymer as a coagulant aid. A discussion of full-scale performance of the alum coagulation process is contained in Chapter 7.

Based on these results, a series of bench-scale jar tests were undertaken in an effort to identify an appropriate polymer which, when used in conjunction with alum, could achieve the required turbidity removal and, if possible, enhance the removal of TOC. Of twenty-one polymers initially considered (Table I.1-2, Appendix I), nine were selected for further screening. Of these, screening tests revealed only four polymers which showed potential for removal of TOC beyond that achieved by alum alone. Table 10.2-1 provides a description of these four polymers. Of these, Betz 1160P produced the highest removals of TOC, and appeared to be the most promising coagulant aid.

Further jar testing with Betz 1160P, however, indicated no significant effect of the polymer with respect to TOC removal compared to removals achieved by alum alone. Similar results were observed at plant-scale, where results with Betz 1160P were not significantly better than previously achieved with the polymer originally supplied during plant start-up (Hercofloc 1018). The relative effect on TOC removal by application of Betz 1160P is illustrated in Figure 10.2-1. Other findings are also illustrated by this figure and were as follows:

1. Turbidity removal increased with dose of Betz 1160P. This agreed with previous plant-scale results with polymers.
2. pH had no consistent effect on turbidity removal.
3. For the alum doses typically used at the EEWTP (40 mg/L and above), optimum TOC removal was observed at a pH of about 6.5.



JAR TEST RESULTS WITH  
50 PPM ALUM/BETZ 1160P  
FIGURE 10.2-1

TABLE 10.2-1

**POLYMERS ACHIEVING SIGNIFICANT TURBIDITY  
REMOVAL AND REDUCTION IN UV ABSORBANCE BASED ON  
PRELIMINARY PRE-SCREENING WITH 10 mg/L ALUM**

<u>Polymer</u>	<u>Description</u>	<u>Optimum Observed Polymer Dose<sup>1</sup></u>	<u>% Turbidity Removal</u>	<u>% UV Abs. Reduction</u>
Betz 1160P	High MW; Low Charge Density; Cationic	0.1	88	23
Magnifloc 572C	Low MW; High Charge Density; Cationic	10.0	92	20
Chitosan	Linear polymer of Chito- biase (crab shells)	0.5	93	19
Hercofloc 815	High MW; Moderate Charge Density; Cationic	1.0	90	20

1. Five polymer doses were tested for each polymer, with doses ranging from 0.02 to 10 mg/L.

The latter observation is in agreement with expectations based on the chemistry of alum coagulation (O'Melia and Dempsey, 1981) and was substantiated by plant-scale results; see Chapter 7.

**Additional Polymer Testing - Coagulant/Filter Aid Selection.** Further tests were conducted utilizing additional anionic and cationic polymers in combination with alum and emphasis was placed on the evaluation of both settled supernatant and filtrate after filtering through a glass fiber filter (see Appendix I). This provided additional consideration of the polymers as filter aids. On the basis of these tests, two additional polymers showed promise. These were both high molecular weight anionic polymers, CA 233 and CA 253, with apparent TOC removals of 38 percent and 31 percent, respectively. As with the Betz 1160P, however, plant-scale implementation of CA-233 revealed little additional TOC removal.

**Alum Coagulation of Influent Sources.** In an attempt to identify the source of the difficulty in coagulating the influent TOC, separate series of jar tests were conducted on the two plant source waters and blended influent, using alum alone at a pH of 6.5. These tests revealed increasing turbidity removal with increased alum dose, but TOC removal was relatively insensitive to dose in all three waters. Filtration of the jar test supernatant indicated that almost all of the TOC not removed was in the dissolved form. Subsequent jar tests were therefore focused on the removal of dissolved organic carbon (DOC).

Additional Testing for DOC Removal - Alum and Polymers as Primary Coagulants. In the final set of alum jar tests, DOC removal was utilized as the criterion for evaluating three additional polymers. These three polymers (Purifloc C-31, Arco 6320 and Arco 6440) were all selected because of their documented performance as primary coagulants for removal of both turbidity and TOC. All are low molecular weight, high charge density cationic polymers. Because these polymers are generally utilized as primary coagulants rather than as coagulant aids, they were not in the original list of polymers considered.

Each of the three polymers was tested both as a primary coagulant and as a coagulant aid in conjunction with alum. Alum alone was also investigated. The tests indicated that none of the polymers could achieve greater DOC removal than that achieved by alum alone, whether used as primary coagulant or in conjunction with alum. At higher polymer doses (above 5 or 10 mg/L), the polymers actually contributed additional DOC to the jar test supernatant.

Summary. Increased turbidity removal could be achieved through the use of increased alum doses and/or the use of a polymer as a coagulant aid. Several polymers were identified which performed well in this regard (Betz 1160P, Hercofloc 1018, and CA 233), all of which were successfully utilized at plant-scale. Removal of greater than forty percent of TOC could not be achieved with any of the alum/polymer combinations tested, even with alum doses as high as 240 mg/L. Removals of 30 to 35 percent of TOC were typical for doses considered to be cost effective. As anticipated, the optimum pH for TOC removal with alum is in the range of 6.5 to 7.0. The majority of the residual TOC following alum coagulation was in the dissolved form and was not removed by subsequent membrane filtration.

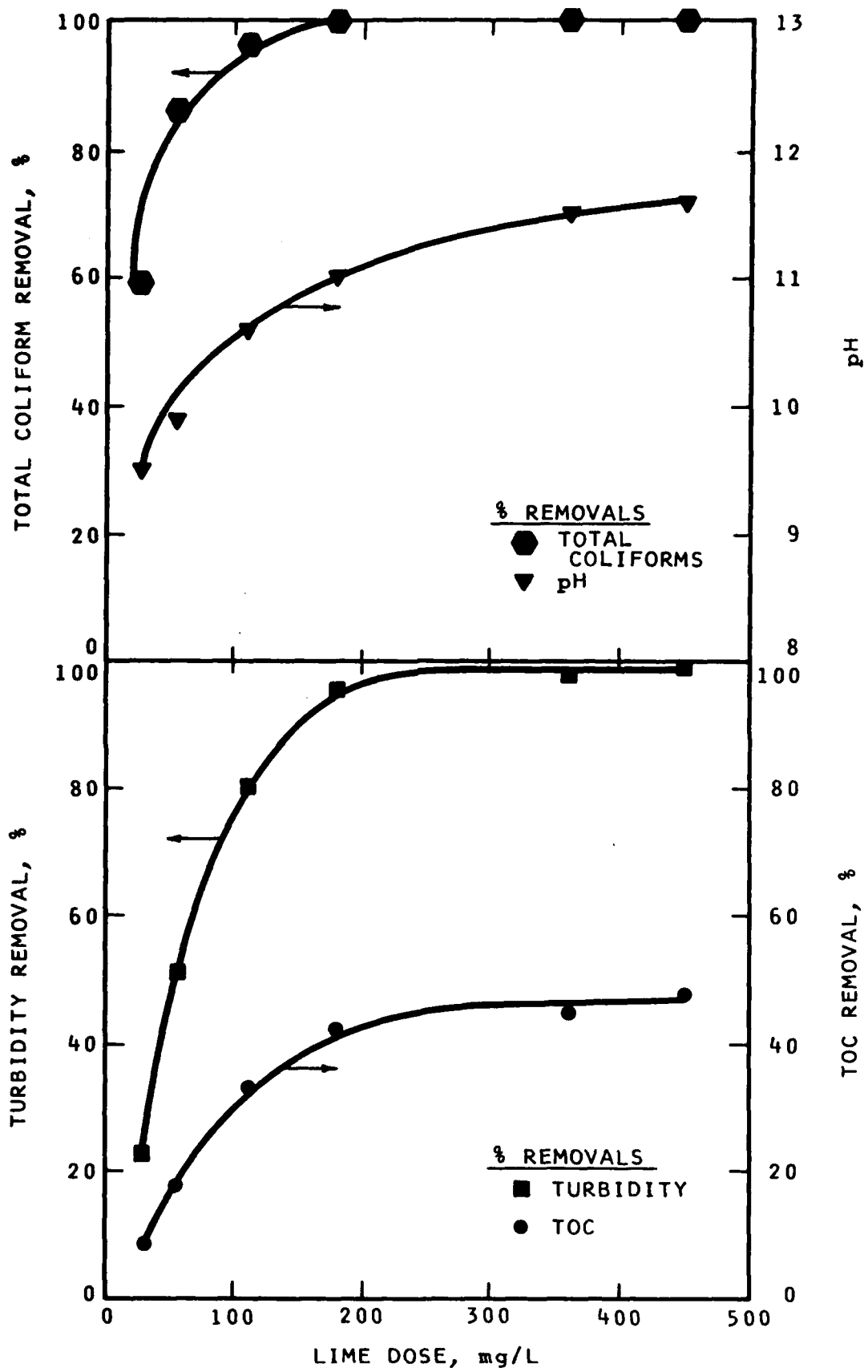
#### Lime Coagulation

Initial jar testing was conducted with lime alone to evaluate the relationship between lime and pH (for the given influent water) and to determine the effect of lime dose on turbidity, TOC, and coliform removal. The results indicated increasing turbidity removal with lime dose, with significant improvements up to a dose of 200 mg/L-CaO. This dose raised the pH to approximately 11.0, as shown in Figure 10.2-2. Under these conditions, coliform levels were reduced from approximately 24,000 MPN/100 ml to non-detectable levels (<2 MPN/100 ml). TOC removal was in the range of 40 to 45 percent, indicating improved removal over that achieved with alum and polymers.

Because influent alkalinity was low, however, the lime doses required to raise the pH resulted in excess calcium ions in the treated water. Specifically, with influent alkalinities in the range of 50 to 60 mg/L-CaCO<sub>3</sub>, calcium concentrations of over 100 mg/L-Ca were measured in the jar test supernatant. Total hardness was on the order of 260 mg/L-CaCO<sub>3</sub>. This level was judged to be unacceptable and alternatives were sought to either increase the available carbonate or decrease required lime doses. Soda ash (Na<sub>2</sub>CO<sub>3</sub>) was tested for the former objective, and polymers and ferric chloride (FeCl<sub>3</sub>) were tested for the latter. The results from these tests are discussed below.

Lime With Soda Ash. Jar tests conducted with lime in conjunction with Na<sub>2</sub>CO<sub>3</sub> indicated reductions in turbidity and TOC removal (relative to lime





JAR TEST RESULTS-LIME AS SOLE COAGULANT  
FIGURE 10. 2-2

## Process Characterization and Optimization

alone) at equivalent lime doses. This was probably due primarily to the increased production of colloidal solids. The lowering of pH by the buffering capacity of the soda ash could also be a factor. As a result, the required lime dose was significantly increased, with doses of 130 mg/L-CaO or more needed to achieve eighty percent turbidity removal. Corresponding soda ash requirements were on the order of 50 mg/L-Na<sub>2</sub>CO<sub>3</sub>. The implications of these doses with respect to chemical cost, sludge volume, and resulting sodium concentrations<sup>1</sup> led to a conclusion that alkalinity addition was not the most cost effective solution. Attention was therefore focused on potential coagulant aids for the reduction of lime dosage requirements.

**Lime With Coagulant Aids.** Jar tests were conducted using lime in combination with six of the polymers tested during the alum phase and previously described. These are listed below.

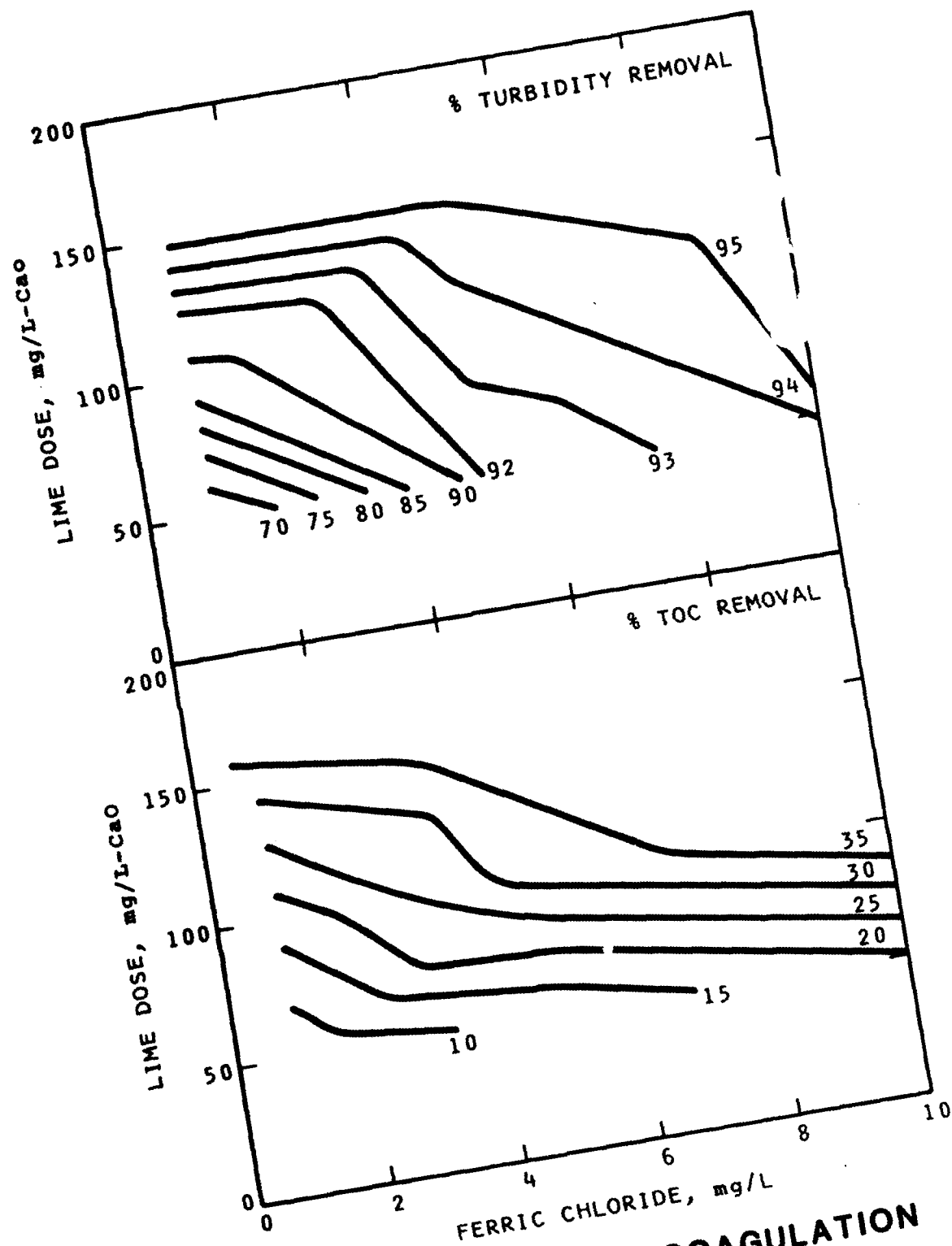
	<u>Charge</u>		<u>Charge</u>
Betz 1160P	+	Hercofloc	-
Magnifloc 572C	+	CA 253	-
Cat Flocc T	+	CA 233	0

None of these polymers showed promise with respect to decreasing the lime requirements. Although some polymers did provide modest increases in turbidity removal (relative to the same lime dose without polymer), TOC removals were actually decreased for all cases.

Tests with ferric chloride, on the other hand, indicated that FeCl<sub>3</sub> improved both turbidity and TOC removals when used in combination with lime. Figure 10.2-3 summarizes the jar test results. pH levels observed during these jar tests were similar to those observed with lime alone, being only one to two tenths lower due to the acidic nature of the ferric chloride.

On the basis of these results, it was decided that acceptable performance could be achieved at lower lime doses with the use of ferric chloride as a coagulant aid. Full-scale application indicated that with 2 mg/L of ferric chloride addition, acceptable turbidity and TOC removal could be achieved with a target pH of 10.75 in lieu of 11.0 with lime alone. This target pH was achieved with lime doses of between 70 and 100 mg/L, depending on influent alkalinity. Several combinations of target pH (lime dose) and ferric chloride dose were evaluated on an experimental basis at plant-scale, with a conclusion that a target pH in the range of 10.5 to 11 was optimum (see Chapter 8). Higher ferric chloride doses indicated a potential for further reduction in lime dose but with resulting trade-offs in terms of bacteriological kill at the lower pH.

1. See Chapter 9 for a discussion of the potential adverse health impacts of sodium in drinking water.



**LIME/FERRIC CHLORIDE COAGULATION  
TURBIDITY AND TOC REMOVALS  
FIGURE 10. 2-3**

## RECOMMENDATIONS

### Alum Coagulation

Study results suggest that further optimization of the alum coagulation process beyond that accomplished in the full-scale tests at the EEWTP is limited with respect to turbidity and TOC removal. With the given influent water an alum dose of between 40 and 60 mg/L should be anticipated, with a requirement for polymer addition to aid in the removal of turbidity, and an optimum operating pH between 6.5 and 7. Three polymers successfully served this purpose during the first year of operation: Hercofloc 1018, Calgon CA 233 and Betz 1160P. All three are high molecular weight polymers of varying structural origin. These three polymers are anionic, nonionic, and cationic, respectively.

### Lime Coagulation

Bench testing indicated that ferric chloride was effective in reducing lime doses for comparable turbidity and TOC removals, relative to the use of lime alone. Six polymers tested indicated that these offer no beneficial effect. The use of higher lime doses without coagulant aid is precluded because of concerns related to finished water hardness. Results indicate that soda ash addition would not be effective in ameliorating this problem and would lead to higher costs, increased sludge volumes, and a potential problem with sodium ion concentrations.

Thus, full-scale operation with ferric chloride as a coagulant aid for lime settling is recommended. Successful operation is achievable with operation to a pH of 10.75, which corresponds to a lime dose of 150 mg/L-CaO, and 2 mg/L of ferric chloride addition. On the basis of results to date, this combination appears to be optimum.

## FILTRATION STUDIES

### BACKGROUND AND APPROACH

The primary objective of the filtration process has traditionally been to remove particulate matter and, thus, decrease the turbidity of the finished water. The EPA Primary Drinking Water Standards dictate that the maximum contaminant level for turbidity is 1 NTU. A more recent concern in the drinking water field is the level of organics in potable water. Therefore, the removal of organic parameters, such as TOC, by the filtration process is of interest. In the case of the EEWTP, TOC removal through filtration may reduce subsequent costs for TOC adsorption on granular activated carbon. Finally, it is desirable to meet the objectives of the filtration process while minimizing costs.

Operational changes, such as increasing the filtration rate and improving the backwash sequence, are capable of improving filter production efficiency and decreasing filtration costs. Filter aids also have the potential for decreasing filter costs, while improving removal of turbidity and/or TOC. During this project, 1 gpm pilot-scale filter modules were utilized to evaluate rates of filtration as well as to screen the potential use of several polymeric coagulant

aids for filter pretreatment. Details of these pilot studies are provided in Appendix I, Section 9. Results are summarized below.

### DISCUSSION OF RESULTS

#### Filtration Rate

Filtration rates of 3, 6, and 9 gpm/ft<sup>2</sup> were studied at pilot scale using the same influent water, bed depth and filter media as utilized during Phase IA at the EEWTP. The results of the filtration rate experiments are shown in Table 10.2-2. For each filter run, the loading rates, time to turbidity breakthrough, time to terminal headloss, unit filter run volume and the headloss development are listed. The unit filter run volume was calculated using the following equation:

$$\text{UFRV} = ((\text{Loading rate, gpm/ft}^2) \times (\text{Filter run time, hrs}) \times (60 \text{ min/hr})) \\ - (\text{Unit backwash volume, gal/ft}^2)$$

The filter run time is the time to turbidity breakthrough (0.2 NTU) or the time to terminal headloss (100 inches H<sub>2</sub>O), whichever is lower. The unit backwash volume was 200 gal/ft<sup>2</sup> for all columns in each experiment. The rate of headloss development was calculated by dividing the headloss at the end of the filter run by the filter run time. Looking at Table 10.2-2, it can be seen that filter run time was usually dictated by turbidity breakthrough. When a filter is optimally utilized, the time to turbidity breakthrough is nearly coincident with the time to terminal headloss. Terminal headloss should occur first.

The optimum filtration rate maximizes the production of water of desired quality and minimizes the associated capital and operational costs. From Table 10.2-2, it appears that a filtration rate of between 3 and 6 gpm/ft<sup>2</sup> will maximize production of the desired quality of water. A filtration rate of 6 gpm/ft<sup>2</sup> would most likely be preferable to 3 gpm/ft<sup>2</sup> since the average UFRV at 6 gpm/ft<sup>2</sup> is only twenty percent less than 3 gpm/ft<sup>2</sup>, but the surface area of the filter could be cut in half. Plant-scale operation was conducted at 6 gpm/ft<sup>2</sup> for several testing periods, as described in Chapters 7 and 8.

#### Filter Aid Studies

Two polymers were selected from previous coagulation bench studies (see Section 1 of this chapter) as potential coagulant aids for TOC removal through filtration. The two polymers tested were Magnifloc 572-C and Pollu-Treat C-31. Each polymer was tested at several doses against control filter runs with no polymer addition. Results did not indicate any significant improvements in TOC removal through filtration with the filter aids. More detailed results are shown in Appendix I, Section 2.

# Process Characterization and Optimization

TABLE 10.2-2  
RESULTS OF PILOT-SCALE FILTRATION RATE STUDY

	Loading Rate, gpm/ft <sup>2</sup>		
	3	6	9
<b>Run No. 1</b>			
Column	1	2	3
Time to turbidity breakthrough, hrs	not reached	23 <sup>a</sup>	8
Time to terminal headloss, hrs	63	30	23
Unit Filter Run Volume, gal/ft <sup>2</sup>	11,140	8,080	4,120
Headloss development, in/hr	1.6	2.6	3.7
<b>Run No. 2</b>			
Column	2	3	1
Time to turbidity breakthrough, hrs	58	18	10
Time to terminal headloss, hrs	77	53	13
Unit Filter Run Volume, gal/ft <sup>2</sup>	10,240	6,280	5,200
Headloss development, in/hr	0.97	2.2	6.2
<b>Run No. 3</b>			
Column	3	1	2
Time to turbidity breakthrough, hrs	47	24	10
Time to terminal headloss, hrs	115	30	23
Unit Filter Run Volume, gal/ft <sup>2</sup>	8,260	8,440	5,200
Headloss development, in/hr	0.98	2.6	4.4
<b>Run No. 4</b>			
Column	1	2	3
Time to turbidity breakthrough, hrs	not reached	26	16
Time to terminal headloss, hrs	66	38	27
Unit Filter Run Volume, gal/ft <sup>2</sup>	11,680	9,160	8,440
Headloss development, in/hr	1.52	2.19	4.06
<b>Run No. 5</b>			
Column	3	1	2
Time to turbidity breakthrough, hrs	not reached	40	14
Time to terminal headloss, hrs	78	40	16
Unit Filter Run Volumen, gal/ft <sup>2</sup>	13,840	14,200	7,360
Headloss development, in/hr	1.28	2.5	5.29
<b>Run No. 6</b>			
Column	1	2	3
Time to turbidity breakthrough, hrs	36	8	2
Time to terminal headloss, hrs	46	not reached	not reached
Unit Filter Run Volume, gal/ft <sup>2</sup>	6,280	2,680	880
Headloss development, in/hr	1.3	2.5	10.5
Average UFRV	10,240	8,140	5,200

a. With the exception of Run No. 6, all filter runs were continued until headloss criterion was met for purposes of comparison. Time to breakthrough of 0.2 NTU turbidity was recorded.

## RECOMMENDATIONS

The filtration pilot studies were not conducted over a sufficiently long period of time or under sufficiently varied influent conditions to allow for specific recommendations for full-scale design. The results did indicate, however, that higher filtration rates (up to 6 gpm/ft<sup>2</sup>) might perform reasonably well, with only slightly reduced unit filter run volumes.

Some testing at higher rates was conducted at EEWTP plant-scale for one week intervals. These results showed somewhat poorer effluent quality and lower UFRV with the alum/chlorination pretreatment. With lime pretreatment, results were roughly comparable to those achieved at lower loading rates. Again, however, test durations were not of sufficient length to draw conclusive results.

Thus, the demonstrated plant-scale filtration rate of 3 gpm/ft<sup>2</sup> is recommended for preliminary cost estimates of a full scale estuary plant. Further testing at higher rates might be warranted, however, prior to actual design.

## SPECIAL GAC STUDY QUALITATIVE STUDY OF COMPOUNDS ADSORBED

### BACKGROUND AND APPROACH

One of the principal roles of the granular activated carbon columns at the EEWTP was to provide a barrier against potential synthetic organic chemicals (SOCs) which might be present in the influent water. There is considerable concern with respect to the presence of such compounds when source waters are contaminated with treated wastewater, as discussed in Chapter 1 and Chapter 9 (Section 7) of this report. Monitoring at the EEWTP for SOCs was conducted at GAC influent, intermediate, GAC effluent, and finished water sites in an effort to evaluate which compounds were present in the gravity filter effluent and how effectively they were removed by the GAC. Twenty-four hour composite samples were taken on a biweekly or triweekly basis (dependent on fraction), with the exception of the seven compounds monitored via liquid/liquid extraction GC, which were analyzed twice per week.

The general issue with respect to SOCs is that some cannot be identified by current analytical techniques (see Chapter 9). There also was the likelihood that certain compounds were present in concentrations below analytical detection limits and that these compounds were being removed by the GAC.

In an effort to investigate these issues, a study was conducted to identify the compounds which were adsorbed onto the lead and lag granular activated carbon columns. The methods utilized for extraction and analysis of the organics from the GAC were developed by the Department of Environmental Sciences and Engineering at the University of North Carolina (UNC) at Chapel Hill (Millington, 1982). Techniques using both solvent extraction (acetone, methylene chloride, and toluene) and thermal desorption were applied, with identification by GC/FID and GC/MS. All compound identifications were confirmed by comparison of the mass spectra and retention indices with standards run on the system. Because extraction efficiencies had not been determined at the time of the analysis, quantitation of substances recovered was not possible. Further

description of the analytical techniques is provided in Appendix L. The reader is referred to work by Millington, (1982) for full details of the procedures.

At the end of Phase IA operation in March 1982, three carbon samples were collected and shipped to the UNC laboratory in Chapel Hill. The three samples were of once regenerated Hydrodarco 816 lignite based carbon which had been subjected to different degrees of usage, as listed below.

1. Unused since regeneration
2. Utilized for five months in the lag carbon column since regeneration.
3. Utilized for five months in the lead carbon column since regeneration.

TOC removal after five months (approximately 15,000 bed volumes) had dropped to approximately twenty percent corresponding to apparent steady state removal. Thus, the GAC was nearly exhausted with respect to TOC adsorption.

### DISCUSSION OF RESULTS

The results from the extraction and analysis of these three carbons are summarized in Table 10.2-3. The study was able to isolate and identify twenty-six compounds in the lead carbon, seventeen of which were also present in the lag carbon column. Ten compounds were identified which had not been previously found with the analytical techniques and sampling frequencies employed during plant monitoring. Eight of these were present in the lag column as well as the lead.

It is important to note that the unused regenerated carbon sample did not exhibit appreciable amounts of substances which were not accounted for by the solvents themselves, as determined by analysis of blank solvent extraction. The compounds listed in Table 10.2-3 are only those seen in the used carbons which were not found in the freshly regenerated carbon. Many more peaks were seen in the chromatograms than could be identified by comparison to standards or to spectra library. Copies of the mass spectra of the unidentified compounds are provided in Appendix I, Section 6, Figure I.6-1.

### SUMMARY AND CONCLUSIONS

This qualitative study was conducted to gain further understanding as to the nature of the organic compounds which accumulated on the GAC and the effectiveness of GAC in removing SOC's from the influent water. The results indicate that GAC was effective to some degree in removing at least twenty-six specific synthetic organic chemicals.

Ten chemicals were identified which had not been previously identified, either tentatively or confirmed, in the EEWTP influent waters. These compounds were most likely present in concentrations below analytical detection limits, and were concentrated and stored over time by the carbon. It is also possible, however, that spikes of these compounds may have passed through the plant unnoticed (i.e., not sampled), or that the compounds were formed on the carbon through reactions between compounds in the water and or the carbon.



# Process Characterization and Optimization

TABLE 10.2-3  
SOCs EXTRACTED FROM GRANULAR ACTIVATED CARBON SAMPLES<sup>1</sup>

Compound	Identified in Carbon Samples		Detected in EEWTP Sample Analysis (Phase IA)	
	Extracted from Lead Column Carbon	Extracted From Lag Column Carbon	Pre-GAC Sites	Post-GAC Sites
Chloroform	X <sup>1</sup>	X	X	X
Dibromochloromethane	X	X	X	X
Bromodichloromethane	X	X	X	X
Dichloriodomethane	X	X	X	X
Bromoform	X	X	X	X
Bromochloroiodo- methane	X	X		
Tetrachloroethylene	X	X <sup>2</sup>	X	X
Chlorobenzene	X	— <sup>2</sup>	X	X
Dichlorobenzene isomers	X	—	X	X
Trichlorobenzene	X	—	X	X
Ethyl benzene	X	X	X	X
C <sub>3</sub> -alkylbenzenes	X	—	X	X
C <sub>4</sub> -alkylbenzenes	X	—	X	X
Benzaldehyde	X	X		
Xylene isomers	X	X	X	X
Cresol isomer	X	X		
Naphthalene	X	X	X	X
Dimethylnaphthalene isomers	X	—	X	—
Methylnaphthalene isomers	X	—	X	—
Benzonitrile	X	—	—	—
Benzophenone	X	—	—	—
Acetophenone	X	X	—	—
Tributyl phosphate	X	X	—	—
Tris-chloroethyl phosphate	X	X	—	—
Tris-butoxyethyl phosphate	X	X	—	—
Diethylphthalate	X	—	X	X
p-Toluenesulphonamide <sup>3</sup>	X	X	—	—

1. "X" indicates that the given SOC was identified in one or more samples from that location.
2. — = SOC was not identified in the carbon sample at this location.
3. Identification not confirmed.

In any event, it is unlikely that chronic doses of any of the additional detected compounds were sufficiently high to be of health concern and the results of this study did not alter the evaluation of EEWTP finished water quality, as discussed in Chapter 9.

### MANGANESE REMOVAL STUDIES

#### BACKGROUND AND APPROACH

At concentrations of a few hundredths of a milligram per liter, manganese may cause buildup of coatings in water distribution systems which, if they slough off, cause unacceptable aesthetic problems to consumers. These include brown or black precipitates, staining of laundry goods, and, at sufficiently high levels, changes in the taste of the drinking water.

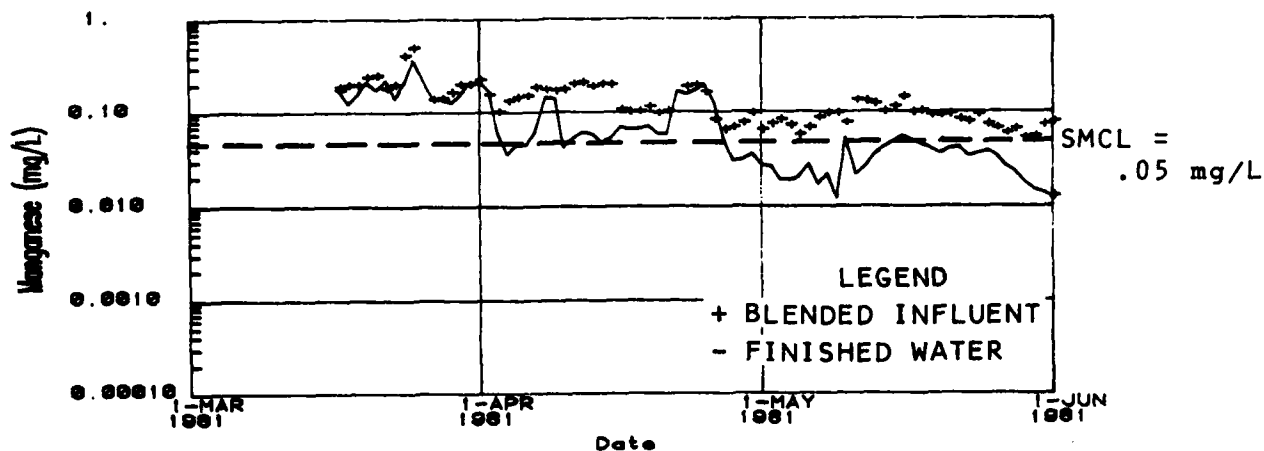
Concentrations of manganese in EEWTP influent water averaged approximately 0.2 mg/L over the course of the two year study, with maximum concentrations approaching 0.7 mg/L. Removal through the treatment plant occurs primarily through oxidation of the manganese to insoluble forms (which are subsequently removed as particulates) and/or sorption and subsequent oxidation of the soluble manganese onto media coated with oxides of iron and manganese. During the first several weeks of operation at the EEWTP, it became apparent that the removal being achieved was not sufficient. Manganese levels in the finished waters exceeded the National Secondary Drinking Water Regulations MCL of 0.05 mg/L on several occasions, as shown in Figure 10.2-4(a).

A study was undertaken to determine a technically feasible and economic method of achieving consistent manganese removal. Treatment alternatives were reviewed and selected alternatives were implemented at full scale. Plant data was evaluated and process variables, such as pH and chemical application points, were altered to optimize removal. Bench-scale testing with potassium permanganate ( $\text{KMnO}_4$ ) was also conducted to assist in evaluating doses for plant operation. Manganese species were tentatively identified in bench tests and at each major stage of treatment in order to identify removal mechanisms and evaluate rates of oxidation. Further description of the tests conducted is provided in Appendix I, together with details of the results. These latter are summarized below.

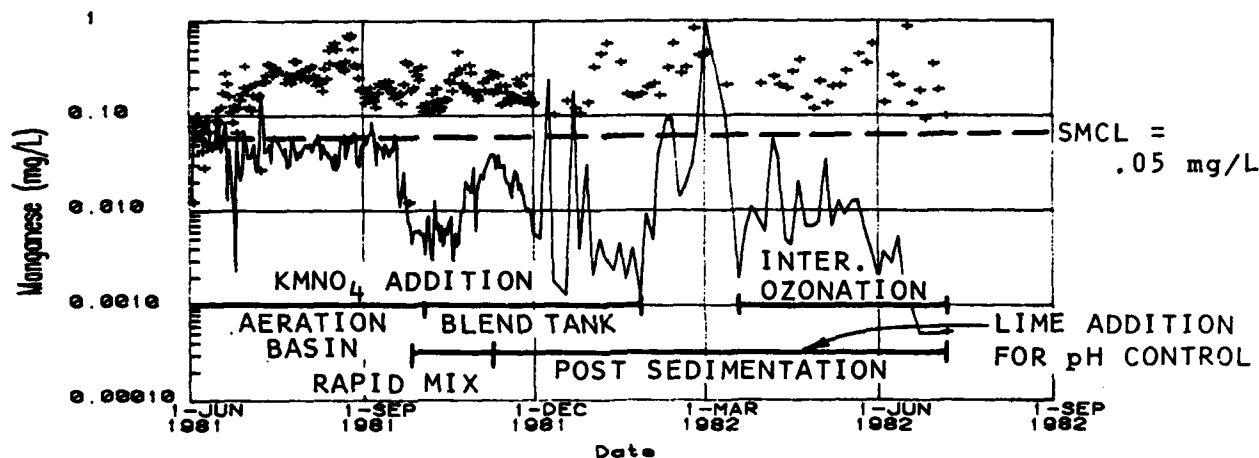
#### DISCUSSION OF RESULTS

##### Alum Phase

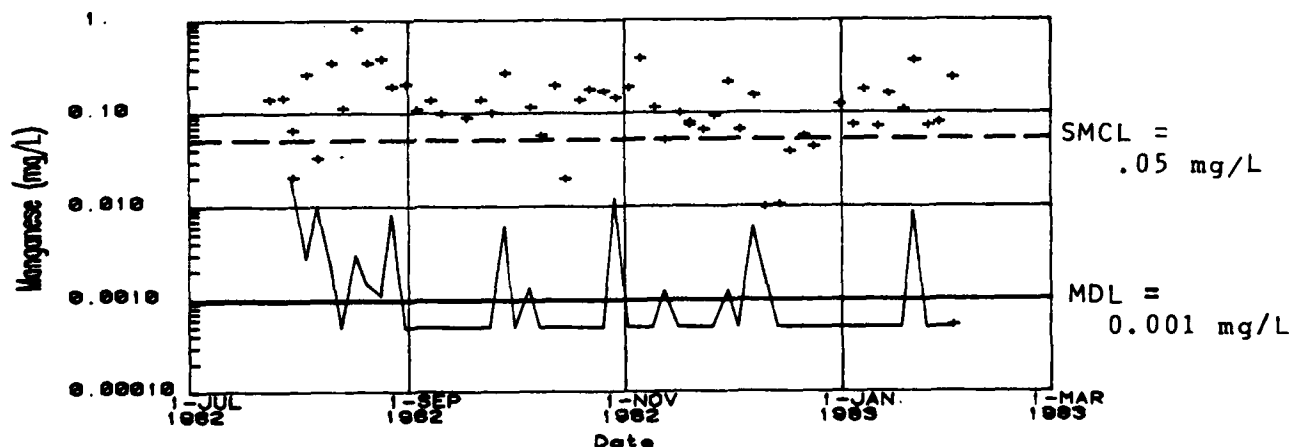
With alum coagulation, the optimum pH for TOC removal during coagulation is in the range of 6.5 to 7.0, as discussed in Section 2 of this Chapter. Because hydrated aluminum sulfate (alum) is an acidic chemical, the pH levels of the generally neutral influent water were lowered to this range by the addition of alum alone and further pH control was not initially practiced. At these pH levels, however, soluble divalent manganese ( $\text{Mn}^{2+}$ ) could not be oxidized rapidly enough to allow subsequent sedimentation or filtration. The only available sources of oxidation were surface aeration immediately prior to rapid mixing, and intermediate chlorination, immediately prior to filtration.



(a) Manganese removal during alum phase without pH control measures



(b) Manganese removal during alum phase with control measures



(c) Manganese removal during lime phase

**MANGANESE REMOVAL  
(PHASES I AND II)  
FIGURE 10. 2-4**

## Process Characterization and Optimization

Because of its purported ability to oxidize manganese over a broad pH range, and its relative ease of application, potassium permanganate ( $\text{KMnO}_4$ ) appeared to be the most reasonable alternative for achieving the required oxidation of the manganese.

Permanganate addition was implemented at several different application points both with and without simultaneous pH control, as described in Chapter 7 and Appendix I. The following general results were observed:

1.  $\text{KMnO}_4$  addition at the blend tank and aeration basin, ahead of the coagulation process, provided significantly better results than when permanganate was added directly to the rapid mix. Formation of insoluble manganese prior to coagulation may allow otherwise stable colloidal manganese oxides to be flocculated into larger particles for subsequent removal. This hypothesis was supported by bench testing.
2. pH adjustment with lime significantly improved manganese removal; this was most noticeable during a short period of operation with pH control prior to coagulation; see Figure 10.2-4(b).
3. pH adjustment prior to filtration provided reliable manganese removal, given conditions of prior permanganate addition. Removal deteriorated when permanganate addition ceased, but was superior to the removals achieved during initial operation without pH control. It should be noted, however, that the previous permanganate addition may have led to iron and manganese coatings on filters and GAC media, allowing subsequent sorption and oxidation of soluble manganese from the process water.
4. Speciation tests indicated that both source waters contained significant concentrations of soluble manganese. Blue Plains nitrified effluent contributed sixty percent of influent manganese under most conditions.
5. Intermediate ozonation provided superior oxidation of soluble manganese to that achieved with chlorination. Manganese concentrations in Phase IB finished waters exceeded the federal secondary MCL on only one occasion.

Figure 10.2-4(b) shows the finished water quality with respect to the various operating phases associated with the above findings.

### LIME PHASE

As documented in Figure 10.2-4(c), the higher pH levels associated with lime coagulation led to excellent oxidation and removal of soluble manganese, without the need for any form of pre- or intermediate oxidant. Manganese concentrations in EEWTP finished water were quite low throughout this period of operation, as shown in Figure 10.2-4(c).

### RECOMMENDATIONS

Manganese removal is a concern which deserves serious consideration with respect to the design and operation of any future estuary water treatment

plant. Soluble manganese levels from both the Potomac estuary and Blue Plains nitrified effluent were relatively high during the monitoring of this study, and levels on the order of 0.2 mg/L have been modeled for the estuary under drought conditions (see Chapter 6).

With alum coagulation, special manganese control measures will be required. As a minimum, allowances must be made for pH adjustment (to 8.0 or higher) prior to gravity filtration. In addition, it may be necessary to add potassium permanganate during start-up or periods of excessively high influent manganese levels, and this process should be included in design. With respect to manganese removal, intermediate ozonation offers some advantage over intermediate chlorination.  $\text{KMnO}_4$  facilities may not be required if the ozonation process is utilized.

If a lime coagulation process is utilized, no special accommodations for manganese control are required. Manganese removal is easily accomplished at the higher pH achieved with the lime mode of operation.

### THM/TOX FORMATION STUDIES

#### BACKGROUND AND APPROACH

When chlorine is used for the disinfection of drinking water, halogenated organics are formed, including total trihalomethanes (TTHMs) as well as other components of purgeable and non-purgeable total organic halides (TOX). Following an assessment of the occurrence frequency, sources and potential health risks of THMs, the EPA promulgated regulations limiting the permissible levels of TTHMs to 0.10 mg/L (100  $\mu\text{g/L}$ ) TTHM. The levels are based on established monitoring procedures that call for sampling at "representative" and "extreme" locations in the water distribution system.

The yield of TTHMs from the reaction of chlorine with organic precursors has been shown to depend on the reaction time, pH, chlorine:TOC ratio, temperature, bromide concentration and the concentration and nature of the organic precursors.

In order to gain an understanding of the kinetics of TTHM and TOX formation in EEWTP water, and in order to evaluate EEWTP water with respect to THM formation potential (THMFP), kinetic rate tests and predictive THMFP batch tests were conducted. The bench testing work is described in detail in Appendix I, Section 8, and is briefly summarized below.

#### Kinetic Tests

The effect of pH and chlorine dose on the kinetics of THM and TOX formation were evaluated by monitoring these parameters over time under carefully controlled experimental conditions, as described in Appendix I. Essentially, all variables except those which were under study were held constant for each experimental run. Finished water samples were analyzed for TTHM or TOX at 0, 3, 30, 100, 1,000, and 10,000 minutes of chlorine contact at four different applied chlorine doses and at four different pHs.

### Predictive THMFP

These series of tests were run to predict the THMFP corresponding to plant-scale operating conditions in the distribution system. Unlike the kinetic test, the pH and chlorine dose for the predictive test were not altered, reflecting actual plant conditions at the time of sampling. Temperature, however, was maintained at a constant level of 25°C. The samples were analyzed for TTHM at sixty minutes and one, four and seven days of chlorine contact time. Finished water samples from the EEWTP (Phase I) and finished water samples from two local WTPs were collected and evaluation for the THMFP associated with each water.

Similar sets of tests were run with samples from the EEWTP gravity filter effluent during both alum and lime phases and on samples from the GAC effluent during Phase II, when ozone/chloramines were used for disinfection. For these tests, chlorine was added to simulate chlorination in order to predict levels of THMs which might be reached if water of this quality were disinfected with free chlorine and entered the distribution system.

## DISCUSSION OF RESULTS

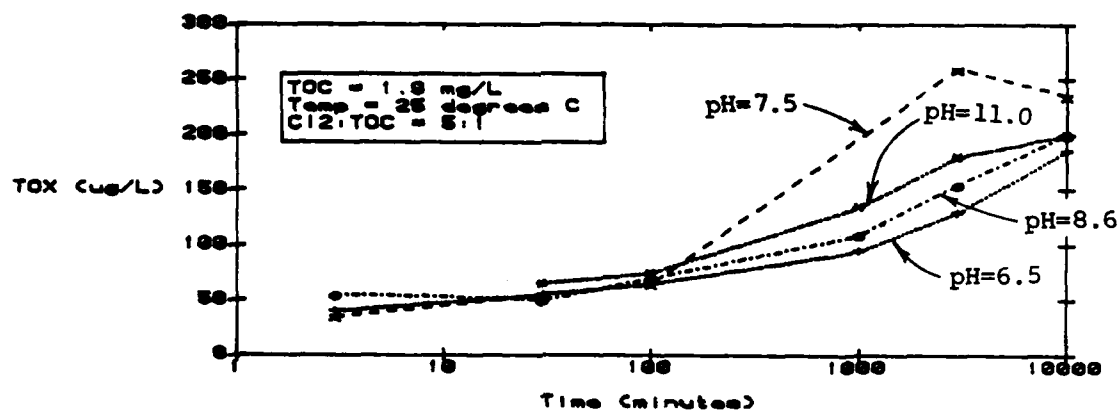
### Kinetic Tests

Results from the TTHM and TOX kinetic tests are shown in Figures 10.2-5 and 10.2-6. As can be seen from Figure 10.2-5, the rate of TTHM formation increases with pH. This agrees with a number of previous findings (Stevens, et al, 1976, Umphres, et al, 1981), although some exceptions have been observed (Morris, et al, 1978). Higher rates of chloroform formation with increased pH have been attributed by previous researchers to the hydrolyzation of chloroform intermediates (Morris and Baum, 1977, Fleischacker, et al, 1982). With respect to TOX, the maximum observed rate of formation occurred at a pH of 7.5, with decreased rates of formation at pH levels above and below this value. However, the data that suggest a maximum TOX formation at pH 7.5 are limited; further testing is recommended.

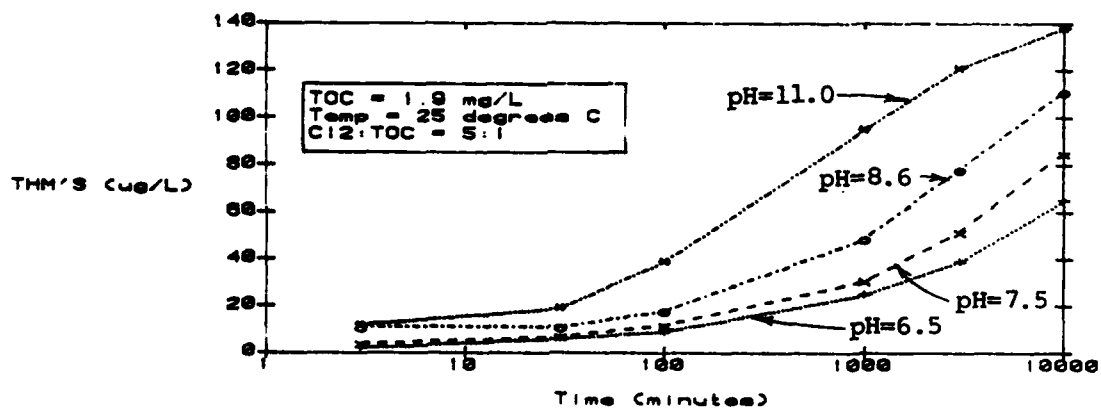
As shown in Figure 10.2-6, rates of TTHM and TOX formation increased significantly with chlorine dose, as anticipated. Maximum production of TTHM and TOX was relatively low, however, with values of 110 and 300 µg/L-Cl respectively, after 10,000 minutes of contact with 14 mg/L of chlorine applied. The low values of terminal THM and TOX are attributable to the low total organic carbon concentration (1.4 mg/L) in the finished water sample. The potential for TTHM formation with different water quality were evaluated through predictive tests, as described below.

### Predictive TTHM

Predictive TTHM tests were conducted to determine terminal TTHM levels after one, four and seven days of chlorine contact under chlorination conditions designed to simulate actual disinfection prior to distribution. Results are summarized in Table 10.2-4. Major conclusions which can be drawn from these results are as outlined below.

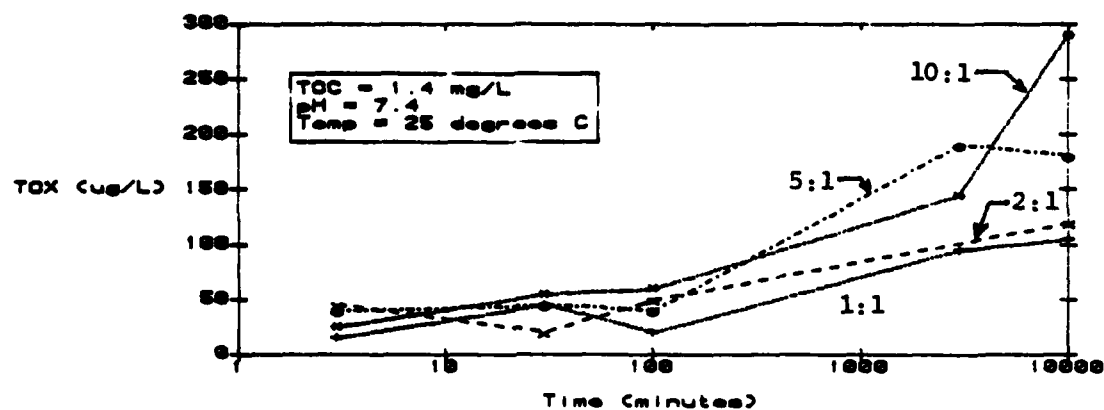


(a) TOX formation over time as a function of pH

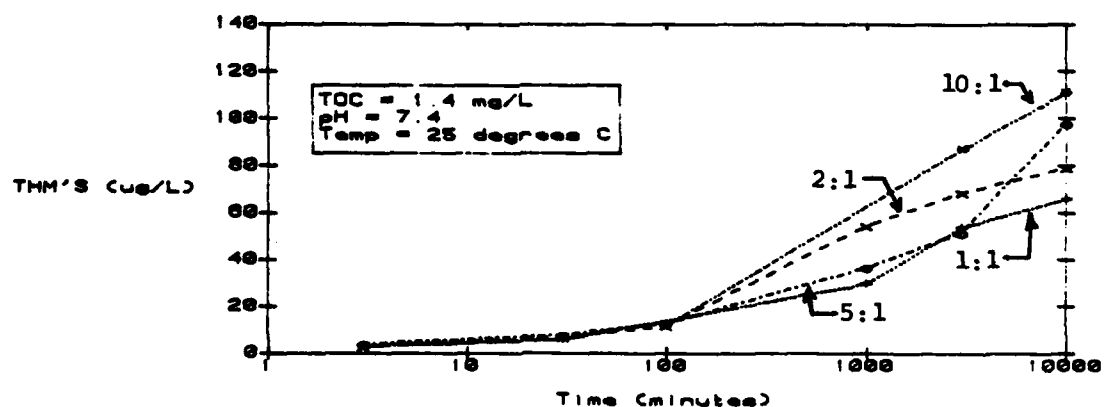


(b) THM formation over time as a function of pH

TOX/THM FORMATION AS A FUNCTION OF pH  
FIGURE 10. 2-5



(a) TOX formation over time as a function of chlorine dose.



(b) THM formation over time as a function of chlorine dose.

TOX/THM FORMATION AS A  
FUNCTION OF CHLORINE DOSE  
FIGURE 10. 2-6



# Process Characterization and Optimization

TABLE 10.2-4

## SUMMARY OF PREDICTIVE THM TESTS

Sample	Chlorination Conditions	No. of Samples	Avg. pH	Avg. TOC	Avg. Terminal TRM (µg/L)		Avg. TTHM/TOC (µg/mg)			
					1-Day	4-Day	1-Day	4-Day	7-Day	
PHASE I										
Gravity Filter Effluent	2-3 mg/L Free Cl <sub>2</sub> after 60 min.	10	7.25	2.87	63.6	88.0	21.5	31.2	30.5	
Finished Water	As chlorinated at EEWTP 2.5 mg/L Free Cl <sub>2</sub> after 60 min.	10	7.71	1.58	56.0	70.1	78.5	36.8	43.8	53.7
PHASE II										
Gravity Filter Effluent	2-3 mg/L Free Cl <sub>2</sub> after 60 min.	3 (in triplicate)	7.65	3.12	71.8	93.3	98.2	23.0	29.6	31.6
GAC Effluent	2-3 mg/L Free Cl <sub>2</sub> after 60 min.	3 (in triplicate)	7.54	1.15	13.8	20.3	24.9	12.2	18.2	22.4
WTP1	As chlorinated at WTP1	13	7.55	2.67	93.6	116.8	124.5	35.0	42.6	47.0
WTP3	As chlorinated at WTP3	10	7.54	2.98	83.1	98.4	104.0	27.7	34.9	37.3

## Process Characterization and Optimization

1. The finished water during Phase I compared favorably to finished water from local WTPs with respect to TTHM at 1, 4, and 7-day. Tests conducted with plant chlorinated water at 25°C indicated total average TTHM levels would be below the federal MCL of 100 µg/L even after seven days of formation.
2. Gravity filter effluent from both process phases also compared favorably to the local supplies, with assumed conditions of 2 to 3 mg/L free chlorine after sixty minutes of contact and a controlled temperature of 25°C.
3. GAC effluent from the lime process, if chlorinated, would have produced lower TTHM levels than any of the other process combinations studied. It should be noted that the lime mode GAC effluent samples were taken after a short period of carbon service, relative to the Phase I finished water, as reflected by the lower average TOC value in Table 10.2-4.
4. The ratio of 7-day TTHM formation to TOC ranged from 22 to 54 µg TTHM/mg TOC for the different EEWTP waters studied, with the higher values observed for waters of higher pH. These ratios suggest that the federal MCL of 100 µg/L TTHM could be consistently met with EEWTP waters having TOC levels of 2 mg/L or less.

### RECOMMENDATIONS

Based on the results of the THM/TOX formation studies, the EEWTP finished water compared favorably to local water supplies with respect to potential 1, 4, and 7-day formation of halogenated organic compounds. Moreover, results suggest that chlorination of gravity filtered water from either phase would also compare favorably, assuming that such chlorination was controlled to maintain no more than 2 to 3 mg/L free chlorine after sixty minutes of contact.

These results suggest that, with respect to meeting federal requirements for TTHMs, the GAC process would not be required. If GAC is to be utilized as a barrier for other synthetic organic compounds, then regeneration should be based on criteria other than the federal MCL for TTHMs.

With respect to plant operating conditions for disinfection, the THM/TOX kinetic tests suggest that THM formation rates are minimized at lower pH levels, while TOX formation rates are minimized at pH levels above and below 7.5. Barring consideration of corrosivity and related concerns with dissolution of metals (see Chapters 7 and 9), the lower range of pH (6.5 to 7.0) might be suggested.

## CORROSION TESTING

### BACKGROUND AND APPROACH

The corrosivity of a finished drinking water impacts the costs for maintaining the distribution system. In addition there is potential health concern related to the dissolution of toxic inorganic substances from distribution piping—most notably, lead and cadmium. Due to the above considerations, the Secondary Drinking Water Regulations include a stipulation that finished waters should be "non-corrosive." None of the existing general corrosion indices provides a consistent indication of corrosion potential for different waters. In cases where unacceptable corrosivity is suspected, special corrosivity testing is recommended and control measures needed.

During initial operation of the EEWTP under the alum phase of operation, pH and alkalinity levels in the finished water were low. This was due primarily to the addition of acidic water treatment chemicals (alum and chlorine) to an influent water of low initial alkalinity and buffer capacity. Calculation of the Langelier Index (see Appendix I) and other corrosion indices indicated that there was considerable corrosion potential in the finished water. pH control of finished water pH was initiated to control this problem, as discussed in Chapter 7. Simultaneously, a corrosion testing program was initiated to determine and evaluate the corrosivity of the plant finished water under various operating conditions. The details of the testing program are described in Appendix I, Section 9.

The method used to evaluate corrosivity was the ISWS Machined Nipple Test, which uses copper, galvanized steel and black iron pipe inserts through which the plant finished water flows. Three sets of inserts were installed in the alum phases of operation (Phases IA and IB); three additional sets were installed in the lime phases. One set of inserts was left in place for twenty to twenty-one weeks during each phase. The second set of inserts was in place for the first eleven to twelve weeks, while the third set was in place for the last eight weeks. Precise time periods and schedules are provided in Appendix I. Weight losses in each insert were determined upon removal and total flow through each insert was monitored. The data obtained provided rates of corrosion as measured by weight loss (grams per square meter per day) and penetration (millimeter per year) for each phase of operation and for two separate time periods within each phase.

### DISCUSSION OF RESULTS

With respect to the three metals tested (copper, black iron, and galvanized steel), weight loss and penetration rates were always highest for black iron and lowest for copper. The Phase II corrosion test results indicate an increase in the corrosion rates for copper and galvanized steel relative to the Phase I results, despite the fact that calculated corrosion indices suggest Phase II is less corrosive than Phase I. Corrosion test results for black iron followed the tendencies suggested by the corrosion indices, Phase I being more corrosive than Phase II.

## Process Characterization and Optimization

Visual observations indicated both the black iron and galvanized steel inserts from both phases had pitting, patchy removal or wearing down of the interior surface. The copper inserts exhibited no visible disruption of the interior surface due to corrosion. Pitting of the interior surface of the black iron inserts utilized during the Phase II test are not well understood, but it is suspected that residual ozone or ozone by-products might be attacking the inserts even after two hours of detention since ozonation. In light of the measured corrosion indices, however, it seems unlikely that similar corrosivity would be observed in the more remote piping of a distribution system.

Specific study results, time periods, and associated measurements of chemical corrosivity indices (buffer intensity, Langelier index, and Larson's ratio) are discussed in further detail in Appendix I, Section 9.

### RECOMMENDATIONS

Using the results from this limited study only several general recommendations can be formulated as listed below:

1. Comparing the results of the corrosion indices calculations with the corrosion test results suggests that rigorous tests should always be conducted to evaluate the corrosional effects of a finished water on specified pipe materials. Corrosion indices can be used as tools for operation; however, their effectiveness for this purpose should first be determined through the corrosion test described herein.
2. The plant-scale test results indicate that Phase I finished water was less corrosive than Phase II water. pH control measures, in the form of lime addition at the sedimentation effluent and sodium hydroxide addition at the GAC effluent, did serve to reduce the corrosivity of the water and are recommended for full-scale application. The efficacy of these measures may be reflected in the relatively low corrosion rates observed in the special study reported here.
3. With respect to Phase II operation, the corrosion indices (buffer intensity, Langelier index and Larson's ratio) suggest the need for additional corrosion control is not necessary. However, corrosion test results indicated a potential for corrosion (including noticeable pitting in black iron) which was not fully resolved. On the hypothesis that such corrosion is related to the use of ozone, the selection of process piping following ozonation should be carefully considered.

### HYDRAULIC CHARACTERIZATION

#### BACKGROUND AND APPROACH

The efficiencies of many water treatment processes depend upon the hydraulic characteristics of the process basins. This is especially true for mixing compartments, flocculation, and sedimentation basins, where the fluid detention time and flow patterns are two of the hydraulic characteristics which most noticeably influence the efficiency of the process.

## Process Characterization and Optimization

In order to characterize the hydraulic characteristics of several of the unit processes at the EEWTP, tracer studies were conducted. Slugs of lithium chloride were injected into process influents and lithium was monitored in the process effluent until substantially all of the tracer had passed through the basin. Details of the injection and sampling locations are provided in Appendix I, Section 10. The following unit processes at the EEWTP were tested:

1. Blend tank
2. Aeration basin
3. Rapid mix tanks
4. Flocculation basins
5. Sedimentation basin
6. Lead and lag carbon columns
7. Chlorine contact tank

Results were plotted in dimensionless terms to provide comparison of hydraulic characteristics with theoretical relationships and typical curves.

### DISCUSSION OF RESULTS

Dimensionless tracer curves for each of the processes monitored have been provided in Appendix I. In general, the results indicate that the hydraulic characteristics of most unit processes are close to the intended design, with the exception of sedimentation, for which there was considerable short circuiting. Individual process results are briefly discussed below.

#### Blend Tank

The results of the test indicate good mixing in the blend tank with an average detention time approximately equal to theoretical. The normalized tracer concentration curve for this process agreed very closely with the theoretical curve for a completely mixed basin, as discussed in Appendix I.

#### Aeration Basin

As with the blend tank, the aeration basin tracer studies closely approximated results anticipated for a single completely mixed reactor. The average detention time of the entire basin is computed to be quite close to theoretical (21 minutes), although the average contact time with the atmosphere during surface aeration was considerably less. This latter would be a fraction of the total contact time, as determined by the fraction of total basin volume being aerated at any given moment.

### Rapid Mix Tanks

The two rapid mix tanks were studied together. Results show that the basin very closely modeled two complete mix reactors in series, with a combined average detention time of approximately two minutes.

### Flocculation Basins

As with the rapid mix tanks, the two flocculation basins were studied in series. These basins were studied on two occasions, once in the winter of 1981 and once in late spring (June 1982). On both occasions, the basins' hydraulic characteristics were indistinguishable from what would be anticipated for two completely mixed reactors in series. Thus, the units performed as designed, with an average total detention time of 41 minutes. The tracer curve peak for the two basins in series occurs at slightly over one half of the detention time, or in about 22 minutes. In order to provide additional reliability to ensure desired mixing for all process water, it is recommended that a larger number of smaller basins be placed in series. Three basins in series are generally sufficient and this approach is recommended for the full-scale plant design; see Chapter 11.

### Sedimentation Basin

The tracer curves for the sedimentation basin indicated poor hydraulic characteristics, with considerably short circuiting. Tracer curves for the effluent from the sedimentation tank effluent are shown in Figure 10.2-7. This plot shows effluent lithium concentrations,  $C$ , divided by the theoretical concentrations for complete mixing throughout the basin,  $C_0$ , as a function of time. The time scale is also dimensionless, and is represented as fractions of theoretical detention time,  $T$ .

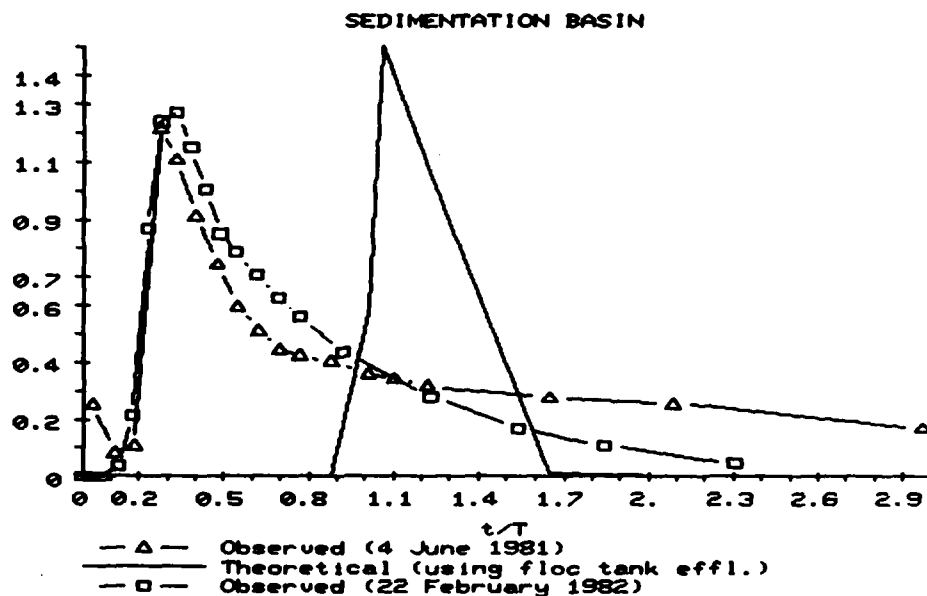
Because tracer was actually added at the flocculation basin influent, the "theoretical curves" for this figure are based on horizontal translation of the flocculation basin effluent basin curve by the detention time of the sedimentation basin. As can be seen from the figure, there was considerably short circuiting under both winter and late spring conditions. The majority of flow is short-circuited with the peak fraction coming through in less than one quarter of the detection time. Over fifty percent of the influent flow has left the basin within two thirds of the detention time.

The poor basin characteristics obviously impaired effective suspended solids removal. Although short circuiting is expected in all basins due to physical conditions (wind-induced, thermal, and density currents), a number of these problems may be eliminated with careful design (Kawamura, 1981).

With proper baffling a sedimentation basin of one half the size (twice the overflow rate) could achieve similar floc detention and settling times.

Fortunately, in the case of the EEWTP, total sedimentation volume was sufficiently large that reasonable removals were achievable despite short-circuiting. With an overall design detention time of 4.5 hours, fifty percent of influent water has a detention of three hours or more. Even the initial peak breakthrough of flow was subjected to a full hour of sedimentation.

C/Co



**SEDIMENTATION BASIN  
 HYDRAULIC CHARACTERIZATION CURVES  
 FIGURE 10. 2-7**

### GAC Columns

Tracer studies of the GAC columns did not reveal any significant short circuiting. The tracer curves very closely model what would be anticipated by assuming that the top half of each column is completely mixed, with perfect plug flow through the actual GAC bed.

### Chlorine Contact Tank

The tracer study of the chlorine contact tank showed a peak concentration of tracer exiting the tank at the theoretical detention time of sixty minutes, with an average detention time slightly greater than this. The peak was relatively sharp indicating the longitudinal dispersion was not excessive. The calculated dispersion number was 0.086. An ideal plug flow reactor would have a dispersion number of zero. As discussed in Appendix I, assumptions of first order disinfection kinetics permit calculations of comparable disinfection relative to perfect plug flow. Assuming 99 percent bacteriological kill, calculations indicate that a dispersion coefficient of 0.086 is roughly equivalent to perfect plug flow with seventy percent of the detention time or, in this case, 43 minutes.

In general, the serpentine configuration of the chlorine contact tank provided reasonable plug flow operation to ensure that all of the water received adequate chlorine contact. In fact, the initial observation of tracer did not occur until after approximately thirty minutes, implying that all water remains in the contact basin for at least that long.

### RECOMMENDATIONS

The principal recommendations from this study relate to the sedimentation process, for which proper baffling should be provided to minimize short circuiting. Fortunately, the sedimentation basin for this project was operated at very low overflow rates (500 gpd/ft<sup>2</sup>) such that performance was adequate. Similar performance should be achievable with full-scale facilities properly baffled and designed for more conventional overflow rates twice as high.

With respect to the other unit processes studied, all facilities functioned essentially as designed with respect to hydraulic flow.



## SECTION 3

### INVESTIGATIONS OF ALTERNATIVE PROCESS DESIGNS

#### INTRODUCTION

The EEWTP finished water quality, as discussed in Chapter 9 of this report, was the product of the combination of unit processes designed and operated at the EEWTP. Although operating criteria were sometimes adjusted in efforts to optimize plant performance, design criteria such as loading rates, contact, or detention times, could not be changed beyond the range of conditions permitted by plant flow. Cost constraints prohibited inclusion of alternative, process facilities, such as packed aeration towers or demineralization equipment such as reverse osmosis, in the 1 MGD process train. Moreover, proper process demonstration dictated that the number of plant scale combinations be limited in order to allow analysis over longer periods of time and different seasons of the year.

With these constraints on plant scale investigation as background, a series of investigations was undertaken at bench scale and at pilot scale on sidestreams of the plant flow. These investigations were aimed at evaluating performance and developing design criteria for potential design modifications to the future estuary water treatment plant which might offer significant cost savings and/or improvements in finished water quality. Alternative design scenarios for GAC adsorption, packed tower aeration, and reverse osmosis were all considered in detail. Summaries of the investigations are provided in the following sections. Details of each study may be found in Appendix I.

#### GAC ADSORPTION

##### BACKGROUND AND APPROACH

With increasing concern over health effects of synthetic organic chemicals (SOCs) in drinking water supplies, a treatment barrier for control of these organic compounds may be necessary if the source is subjected to contamination. Adsorption onto granular activated carbon (GAC) is one such barrier and was the principle SOC barrier employed at the EEWTP.

While GAC may be considered as a viable option for controlling organic contaminants, it is also one of the most costly processes to construct and operate. GAC regenerating costs are particularly important in determining overall costs of water production. Preliminary cost estimates for this project indicate that GAC would be responsible for up to fifty percent of total annual treatment costs for a 200 MGD estuary plant. Optimization of the GAC

## Investigations of Alternative Process Designs

process with respect to operation and design parameters is important for the production of an economically feasible process option.

In this light, an extensive investigation of the GAC adsorption process was conducted at the EEWTP. The emphasis of the investigation was targeted toward resolution of the two fundamental issues listed below.

1. Optimization of GAC Design. Choice of carbon and selection of empty bed contact time are two important aspects of design which can significantly effect treatment costs and finished water quality. These criteria were evaluated using GAC bench, pilot, and computer modeling work for several treatment objectives, as discussed below.
2. Evaluation of GAC Usage Rates. As discussed in Chapters 7 and 8, the EEWTP utilized two GAC contactors in series which were operated to ensure that consistent breakthrough in excess of 2.0 mg/L TOC did not occur. However, alternative criteria for carbon regeneration may well be recommended for full-scale plant operation. In addition, blending of the effluent from numerous parallel contactors in a full-scale facility would dampen out effluent fluctuations of TOC concentration which are observed for single columns. Consideration of alternative regeneration criteria for GAC operation is thus an important aspect of GAC evaluation. This issue was addressed in this study through the use of calibrated and verified GAC breakthrough modeling, combined with mathematical simulation of parallel operation. Because of its flexibility, computer modeling of GAC has the important added benefit of permitting future evaluation of carbon usage with different influent quality and/or updated treatment objectives.

Fundamental to the consideration of both of these issues is the question of regeneration criteria for the carbon operation. Specifically, it is important to identify which parameter(s) should be monitored in deciding when to regenerate the activated carbon, and, as noted above, what level of concentration is considered an "acceptable" treatment objective. As previously noted, EEWTP operation was based on an effluent TOC criteria for the single column, of 2 mg/L. Given an absence of other compounds of identifiable health concern, this goal was selected primarily to ensure that subsequent formation of trihalomethanes by free chlorine disinfection would not exceed the federal MCL of 100 µg/L. However, it was also determined, based on available information, that this mode of operation was conservative with respect to breakthrough of significant concentrations of identifiable SOC's.

For purposes of generating design criteria and carbon usage rates, TOC was also selected as the parameter to be utilized for adsorption characterization and modeling. The rationale for this selection is discussed below.

### Selection of Surrogate Parameter for Evaluation and Modeling

A broad spectrum of organic compounds are removed by GAC, with varying rates of adsorption and with competition among compounds for open adsorption sites. Breakthrough of a compound into the effluent from the column will be

dependent upon the influent concentrations and physical/chemical properties of the compound being considered, as well as the concentrations and properties of the other competing parameters. No single SOC was observed in significantly high levels in EEWTP influent waters, and risk of future estuary contamination with respect to SOCs is largely unknown. In general, there is no guarantee that operation with respect to any given compound will ensure conservative operation with respect to other contaminants. Moreover, the number of SOCs which are amenable to analytical detection, while increasing rapidly, is somewhat limited, and analytical costs are high.

With these considerations in mind, a surrogate parameter is desirable for monitoring and controlling plant processes, and the same parameter should be used for experimental and design work. An appropriate surrogate parameter is one which is readily analyzed and which will provide conservative criteria with respect to GAC breakthrough. In other words, the selected regeneration criteria should be exceeded well before the breakthrough of individual contaminants will occur. Because TOC is always present in significant concentrations in influent water, and because TOC is comprised primarily of large molecular weight, slowly adsorbing molecules, it is likely that TOC will appear in carbon column effluent well in advance of most SOCs of concern. Through selection of an appropriately low treatment objective, conservative operation should be assured. For these reasons, TOC was chosen for experimental and design work for this study and alternative design criteria were evaluated through the modeling of this parameter.

Because TOC has not been evaluated in terms of health effects and/or risks, it is important that final TOC criteria for design be sufficiently conservative to ensure that the GAC process provides an effective organics barrier. For this reason, a range of TOC goals was utilized in developing process design criteria. In addition, a specific SOC of concern (PCE) was selected for independent evaluation at the optimum carbon design. Adsorption parameters for PCE were determined.

Details of the experimental approach for the overall adsorption study are provided in Appendix I, Section 3. An overview is provided below.

### Experimental Approach

To develop a methodology for analysis and design of the GAC adsorption process, a literature review was conducted to evaluate historically accepted design and regeneration criteria, adsorption capacities of typical carbons for compounds of interest, factors which affect GAC performance, and available models for mathematical simulation of the process. On the basis of this review, it was determined that computer modeling was the most appropriate means for evaluating the cost effectiveness of various design and operating parameters, including empty bed contact time (EBCT), type of carbon, contactor configuration, effluent regeneration criteria, and pretreatment (alum/polymer versus lime coagulation). The use of such a model, when properly calibrated by bench work and verified through pilot and full-scale operation, allows the consideration of a wide range of scenarios, beyond those specifically examined with pilot operation. For example, a properly calibrated model can be used at a future

## Investigations of Alternative Process Designs

date to evaluate updated projections of influent water quality and/or revised design criteria. Because of this flexibility of application, and because of the general lack of full-scale GAC operating experience for drinking waters in the United States, an approach was sought which would allow the plant scale and pilot scale results from the EEWTP to be integrated into a general application.

The model selected for use was the Homogeneous Surface Diffusion Model (HSDM), developed from an original adsorption model (Crittenden and Weber) by Thacker, Crittenden, and Snoeyink at the University of Illinois (1980), and subsequently modified by Crittenden et al. Dr. John C. Crittenden of Michigan Technological University was retained as the project consultant for the GAC experimental and modeling work, and a detailed experimental approach was developed.

Selection of the HSDM was based on its applicability to produce information pertaining to the evaluated design parameters, its user oriented format, and its apparent success in prior modeling efforts. However, previous experience with the HSDM had primarily involved the development of HSDM parameters for specific adsorbates such as humic acid fractions or specific SOCs. Therefore, to enhance the capability of the HSDM to accurately model adsorption of the complex collection of compounds which comprise TOC, an experimental program was established to define TOC adsorption parameters for the model. A description of the main assumptions incorporated in the model are provided in Appendix I, Section 3. The detailed experimental plan and results are also provided in that section.

The experimental plan included a series of bench scale tests (isotherm tests, rate studies, and short term column tests) to determine appropriate model parameters for the adsorption of TOC from alum and lime coagulated plant waters onto the three selected carbon types. Simultaneously, 1 gpm GAC pilot columns were operated with each of three carbons at EBCTs and loading rates selected to simulate full-scale operation. These pilot studies were utilized to verify the previously determined model parameters. In most cases, additional calibration of the adsorption capacity parameter (K) was also required, as discussed in Appendix I. Final verification of the model against plant scale results was possible for the one piloted carbon which was used at the EEWTP (Calgon F-400).

The verified computer model was then utilized to calculate carbon usage rates for the selected carbon at three different EBCTs using three different treatment objectives. Usage rates for both single contactor regeneration and for blended operation of parallel columns were considered. These usage rates, combined with capital, operating, and carbon regeneration cost estimates, allowed economic evaluation of the various scenarios.

In addition to optimization of GAC adsorption for TOC, as discussed above, a selected SOC was evaluated to determine the effectiveness of GAC as a barrier in a competitive adsorption situation. Adsorption of the selected SOC, tetrachlorethene (PCE) was evaluated in two ways.

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1. A PCE spiking study was conducted in order to evaluate the possible desorption of other SOC's due to preferential adsorption of PCE. Break-through information with respect to PCE was also sought. A spike of over 1,000  $\mu\text{g/L}$  of PCE was introduced into the influent of pilot carbon columns which had been on-line for five months and were exhausted with respect to TOC.
2. Isotherm parameters were determined for PCE using bench-scale tests, as described in Appendix I. The isotherm parameters, combined with literature based rate constants, permitted computer modeling of this compound. It was intended that the computer model could be verified through the pilot testing described above. Because the carbons tested effectively adsorbed the influent PCE, PCE was never observed in the pilot-column effluent and the model could not be utilized as described.

Full details of the experimental plan and methods for the PCE bench-scale and pilot-scale evaluations are provided in Appendix I, Section 3.

### DISCUSSION OF RESULTS

Results from the GAC study are discussed separately for the following areas of investigation:

1. Independent determination of HSDM adsorption parameters from bench tests
  - $K$ ,  $1/n$  for Freundlich isotherm equation (see Table 10-3.1) from isotherm tests.
  - Mass transfer coefficients for HSDM from differential column rate tests.
2. HSDM calibration and verification, using "mini-column", pilot- and plant-scale GAC column results.
3. Application of HSDM to design.

### Bench-Scale Results and Parameter Estimation

Isotherm Results. Seven day isotherm tests using pulverized granular activated carbon were run for TOC adsorption on three separate carbons, under conditions as described in Appendix I. Each carbon was evaluated using water from two pretreatment conditions.

1. Alum/polymer coagulation, sedimentation, chlorination, and filtration.
2. Lime coagulation, sedimentation, and filtration.

Results are shown in Table 10.3-1.

TABLE 10-3.1

## TOC ISOTHERM RESULTS FOR EEWTP WATERS

<u>Carbon</u>	<u>Adsorption Capacity, K</u>	<u>Adsorption Intensity, 1/n</u>	<u>Non-Adsorbed TOC, C<sub>x</sub>, mg/L-C</u>
<b>Alum Polymer Pretreated Water:</b>			
F-400 (bituminous)	72.7	1.03	0.6
WV-G (bituminous)	60.6	0.76	0.6
HD-4000 (lignite)	48.4	1.02	0.6
<b>Lime Pretreated Water:</b>			
F-400	59.1	1.10	0.85
WV-G	55.0	1.12	0.90
HD-4000	45.4	1.12	0.90

## 1. Parameter estimates for the Freundlich isotherm equation:

$$q_e = K C_e^{1/n}$$

where:

$$q_e = \text{surface equilibrium capacity, mg/gm} = \frac{(\text{vol. of water}) (C_o - C_e)}{\text{mass of PGAC}}$$

K = adsorption capacity

1/n = adsorption intensity

C'<sub>o</sub> = initial TOC concentration at time = 0, mg/L-C

C'<sub>e</sub> = equilibrium TOC concentration, mg/L-C

C<sub>x</sub> = non-adsorbable fraction of TOC, mg/L-C

C<sub>o</sub> = C'<sub>o</sub> - C<sub>x</sub> = initial TOC concentration corrected for non-adsorbed fraction

C<sub>e</sub> = C'<sub>e</sub> - C<sub>x</sub> = equilibrium TOC concentration corrected for non-adsorbed fraction.

Because of the variability in the nature of TOC in different water samples, each test was conducted on three different water samples. Results shown in Table 10.3-1 represented a least squares line fit to the combined data from the two most consistent runs for each carbon/source water combination. Isotherm plots are shown in Appendix I.

The results indicated a non-adsorbed fraction of TOC between 0.6 and 0.9 mg/L with the higher values observed for the lime pretreated water. For a given source water, the non-adsorbed fraction of TOC was consistent between carbons.

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The  $1/n$  values for TOC adsorption are all approximately equal to 1.0 except for the alum/polymer, WV-G value which was estimated at 0.76. A value of 1.0 for  $1/n$  represents a linear isotherm. Similar results have been found by Lee (1980) in experimental work with commercial humic acid. In addition, Cannon and Roberts (1982) conducted adsorption experiments with DOC from treated wastewater and also found  $1/n = 1.0$ . Pirbazari (1980) tested humic acid and found lower values of  $1/n$ , 0.1 to 0.2 lower than those shown for the alum/polymer, WV-G work from this project.

The K values reported in Table 10.3-1 are four to seven times higher than values as reported in a review of full-scale GAC operating experience (Roberts and Summers, 1982). Similarly, equilibrium capacities,  $q_e$ , associated with a particular  $C_e$ , such as 2.0 mg/L-C, for the EEWTP bench rate work ( $q_e=98$  to 148 mg/gm at  $C_e=2.0$  mg/L) are approximately five to ten times higher than the value reported by Roberts and Summers (1982) ( $q_e=16$  mg/gm at  $C_e=2.0$  mg/L).

Isotherm parameters were also developed for PCE as discussed in Appendix I. These parameters, developed only for the alum/polymer pretreated water, are shown in Table 10.3-2. In this case, the isotherm results did not indicate any non-adsorbable fraction and  $C_x=0$ .

TABLE 10.3-2

### PCE EQUILIBRIUM ADSORPTION PARAMETERS ALUM/POLYMER PRETREATED WATER

Carbon	<u>K</u>	<u>1/n</u>	<u>C<sub>x</sub></u>
F-400	713.4	0.48	0
WV-G	784.6	0.62	0
HD-4000	465.6	0.48	0

**Differential Column Rate Test.** The HSDM includes two primary components of resistance to mass transfer, liquid film transfer and surface diffusion within the micropores. The coefficients for film transfer and surface diffusion are  $k_f$  and  $D_s$ , respectively. In the differential column test, flowrates were increased to the point that liquid phase mass transfer resistance was negligible and adsorption became insensitive to the value of  $k_f$ . This allows accurate determination of  $D_s$ .  $D_s$  values determined by the rate tests of this study are shown in Table 10.3-3. These  $D_s$  values were determined from a least squares error curve fit to results from the rate experiments. All rate studies were conducted on water samples taken during the same time period as samples for the isotherm tests. Isotherm parameter values were assumed as previously presented in Table 10.3-1. Values assumed for  $k_f$  are as shown in Table 10.3-3, and were also based on the least squares error fit. The model is quite insensitive to  $k_f$  for the differential column test, and  $k_f$  values were later modified based on additional small column testing, as described below. Because the rate test

## Investigations of Alternative Process Designs

results were quite insensitive to  $k_f$  (see Appendix I), the approximations shown in Table 10.3-3 are sufficiently accurate to allow accurate determination of  $D_s$ .

TABLE 10.3-3

### RESULTS FROM DIFFERENTIAL COLUMN RATE TESTS

<u>Carbon</u>	<u>Assumed Film Transfer Coefficient, <math>k_f</math> (cm/sec)</u>	<u>Determined Surface Diffusion Coefficient, <math>D_s</math> (cm<sup>2</sup>/sec)</u>
<u>Alum Polymer Pretreated Water</u>		
F-400	$1.9 \times 10^{-2}$	$3.5 \times 10^{-11}$
WV-G	$1.0 \times 10^{-2}$	$4.9 \times 10^{-10}$
HD-4000	$1.4 \times 10^{-3}$	$2.8 \times 10^{-10}$
<u>Lime Pretreated Water</u>		
F-400	$2.4 \times 10^{-3}$	$1.1 \times 10^{-10}$
WV-6	$2.8 \times 10^{-3}$	$4.7 \times 10^{-10}$
HD-4000	$1.4 \times 10^{-3}$	$1.0 \times 10^{-10}$

### Model Calibration and Verification

Mini-column Results. The HDSM parameters previously applied were tested against effluent results from short term (24-hour) column tests conducted with 1 in. diameter columns. Water tested was the EEWTP filter effluent, taken during the same time period as samples for isotherm and rate bench tests (see Appendix I). The results from these tests indicated a need for calibration of the film transfer coefficient,  $k_f$ , which had previously been estimated. The final  $k_f$  calibration results are presented below together with additional calibrations from pilot-scale work, in the following section.

Pilot-column Results. Isotherm parameters, surface diffusion coefficients, and film transfer coefficients previously determined from the isotherm, rate, and mini-column tests, respectively, were used for initial modeling of the 1 gpm filter modules. The columns were operated over periods of several months with each carbon and on each source water. Initial model runs produced curves which did not fit the experimental pilot data as well as desired. Sensitivity analyses were conducted on  $K$ ,  $D_s$  and  $k_f$  to determine which parameter(s) needed adjustment.  $1/n$  was not included in this analysis because, as discussed in the isotherm results, the values determined agree with those documented by others (Cannon and Roberts, 1982 and Lee, 1980).



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The sensitivity analyses, described in full in Appendix I, indicated that the results were most sensitive to the adsorption capacity parameter,  $K$ , and that this parameter had apparently been overestimated by the bench work.  $K$  was therefore varied as required to obtain a least squares best fit of the model curve to the experimental data from the pilot columns. The non-adsorbed TOC fraction was also lowered by approximately 0.2 mg/L to more closely fit the observed results. The final model calibration results are shown in Figure 10.3-1 for the lime-pretreated water with F-400 GAC. Data points on this curve are the observed data from the pilot-column. The curve shown is as generated by the HSDM model parameters shown in Table 10.3-4. Model parameters for the other carbons and source water are also shown in Table 10.3-4.

TABLE 10.3-4

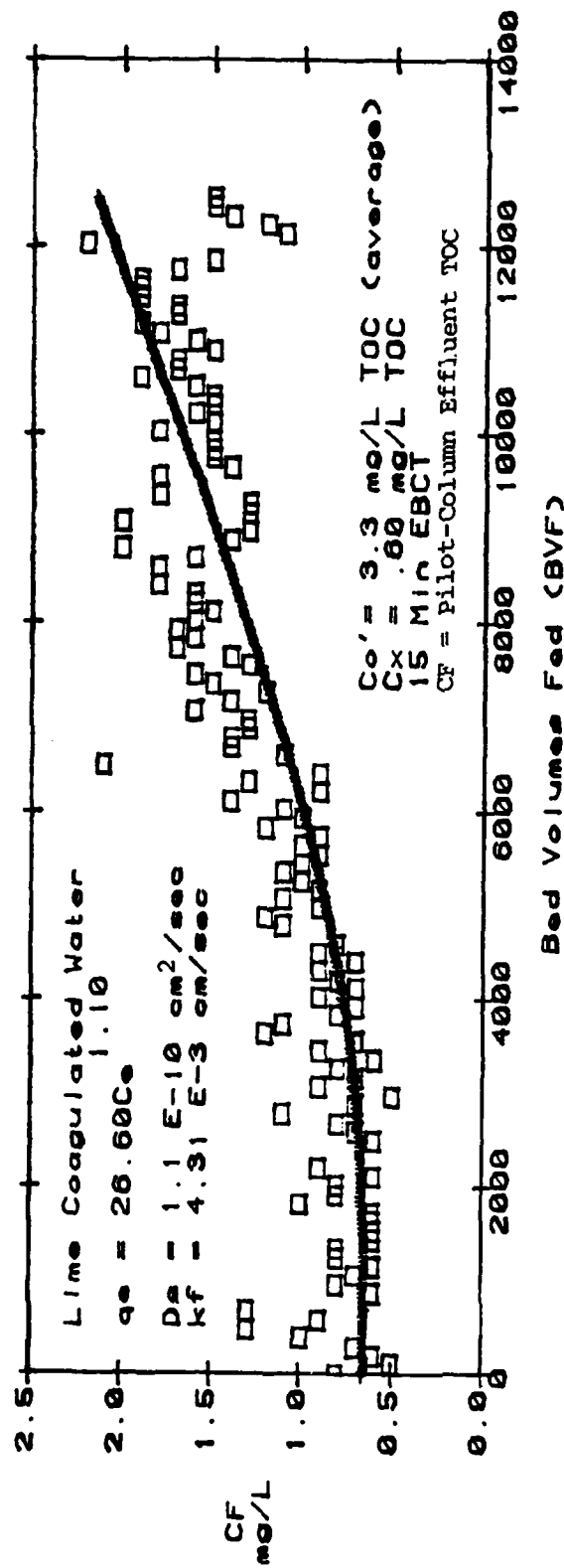
### ADSORPTION PARAMETERS FOR THREE CARBONS AND TWO PRETREATED WATERS

<u>Carbon</u>	<u>K</u>	<u>1/n</u>	<u><math>D_s</math> cm<sup>2</sup>/sec</u>	<u><math>k_f</math> cm/sec</u>	<u><math>C_x</math> mg/L-C</u>
F-400					
alum/polymer	54.53	1.03	3.5E-11	1.74E-3	0.4
lime	26.60	1.10	1.1E-10	4.31E-3	0.6
WV-G					
alum/polymer	45.45	0.76	4.9E-10	199.E-3	0.4
lime	24.75	1.12	4.7E-10	4.31E-3	0.7
HD-4000					
alum/polymer	26.62	1.02	2.8E-10	2.32E-3	0.4
lime	22.70	1.12	1.0E-10	5.22E-3	0.7

Additional pilot studies with long empty bed contact times (30 and 60 minutes) confirmed the non-adsorbed fractions of 0.4 to 0.7 mg/L TOC summarized in Table 10.3-4. These studies, conducted over a two-month period, were not of sufficient duration to be effectively utilized for model verification. Model results did reasonably predict the first two months breakthrough data, however, as discussed in Appendix I.

Pilot studies with tetrachloroethylene (PCE) spiking of a pilot column exhausted for TOC indicated that PCE concentrations of 1.1 to 1.5 mg/L for five days of feeding were fully adsorbed by the carbon, and did not desorb during five days of continued operation without spiking. Other organic compounds which had been previously adsorbed over the course of the pilot operation were not observed in increased concentration in the column effluent during the ten days of the PCE spiking study. Compounds monitored included trichloroethylene, carbon tetrachloride, and the trihalomethanes. These results indicated that the

# F-400 Lime TOC Pilot-Column



□ Experimental Data  
 + Model Run With  $K = 45\% \text{ K From Isotherm Best Fit}$

GAC PILOT-COLUMN TEST  
 (PHASE II)  
 FIGURE 10. 3-1

## Investigations of Alternative Process Designs

GAC was far from exhausted with respect to those compounds, after being fed over 17,000 bed volumes of filtered water from the EEWTP.

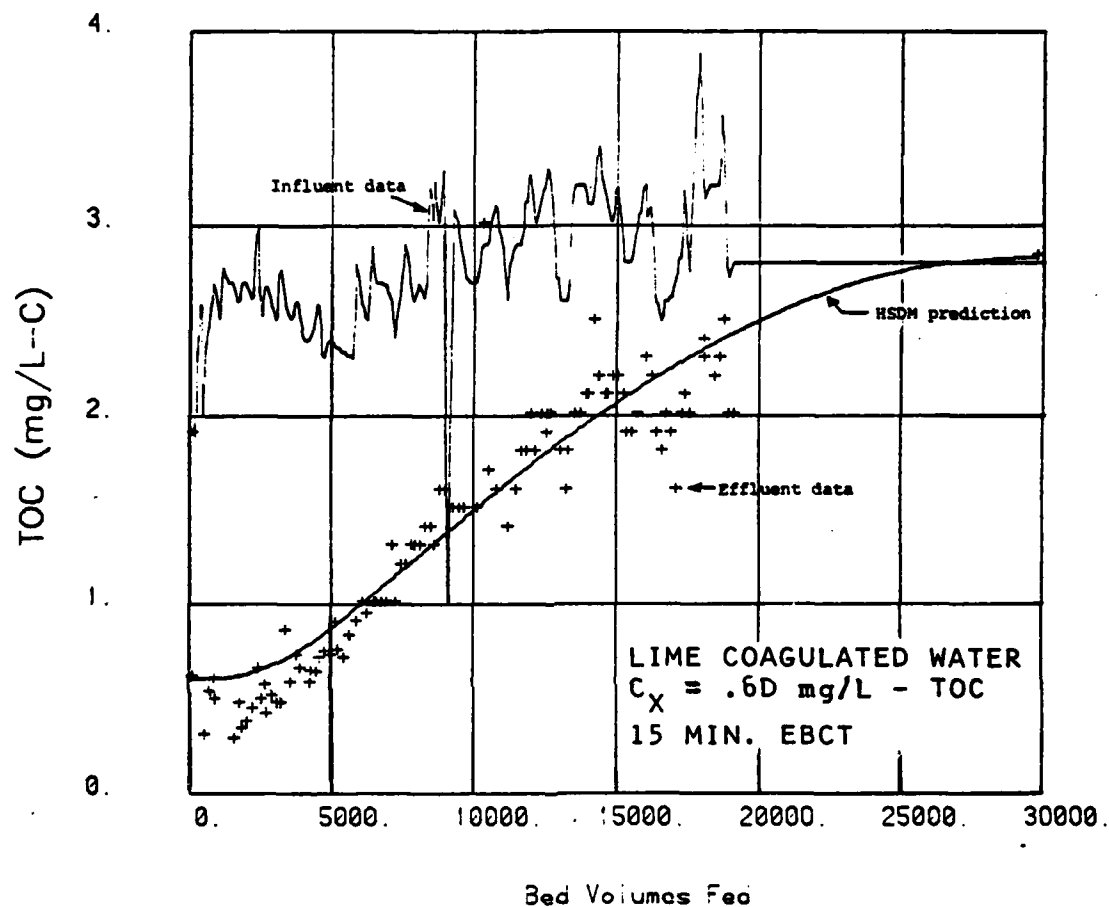
Full Scale Model Verification. Verification of the HSDM calibration results shown in Table 10.3-4 was only possible for the F-400 results on lime treated water, as this was the carbon utilized at plant scale during the lime phase of operation.<sup>1</sup> Model verification for the lime system with F-400 is shown in Figure 10.3-2. The predicted effluent history or breakthrough curve using the HSDM compares quite well with the actual TOC data from the lead GAC column operated in Phase IIA with lime pretreatment.

### Application to Design

The calibrated and verified adsorption model was utilized to evaluate alternative EBCTs for three different potential treatment objectives. Using the HSDM, alternative design scenarios were evaluated and usage rates determined. Emphasis was placed on (1) determining the optimum EBCT for a given treatment objective, and (2) determining the cost savings associated with operating a number of carbon columns in parallel with a treatment objective applied to the blended effluent. For this latter objective, modeled breakthrough curves from single columns were synthetically blended with a computer algorithm. Staggered regeneration of the individual parallel columns was thus simulated.

Carbon Selection. For the evaluation discussed above, time and budget constraints made it necessary to limit the evaluation to one selected carbon. Calgon F-400 was selected for evaluation for the following reasons:

1. F-400 was the only carbon for which full-scale verification of the model was possible.
  2. F-400 (along with WV-G) is a bituminous based carbon with relatively high density. This allows a larger mass of carbon to be installed in the same volume of contactor. Although initial carbon costs would be higher, initial results indicate that lower usage rate (lbs/MG) would more than compensate. In addition, the harder bituminous based carbons are less subject to attrition during conveyance and transport for regeneration.
  3. Of the three carbons examined, estimated equilibrium capacities (mg TOC/gm carbon) were highest for F-400.
- 
1. The carbon utilized during the alum/polymer operation was ICI HD-816, a lignite based carbon which has since been discontinued and was unavailable for the pilot test work.



**TOC BREAKTHROUGH CURVE  
 PLANT-SCALE, F-400  
 (PHASE II)  
 FIGURE 10. 3-2**

## Investigations of Alternative Process Designs

**Usage Rate Calculations.** Usage rate calculations were based on HSDM breakthrough curves generated for each EBCT and each assumed treatment objective. For consistency of comparison, treatment objectives were selected for adsorbable TOC concentrations of 0.5 mg/L, 1.0 mg/L and 1.5 mg/L. These corresponded to total TOC criteria of 0.9, 1.4 and 1.9 mg/L for F-400 adsorption of alum/polymer phase treated water. Equivalent total TOC criteria for the lime phase are higher due to a larger non-adsorbed fraction. In this case, total TOC treatment objectives for the F-400 carbon were assumed at 1.1, 1.6 and 2.1 mg/L.

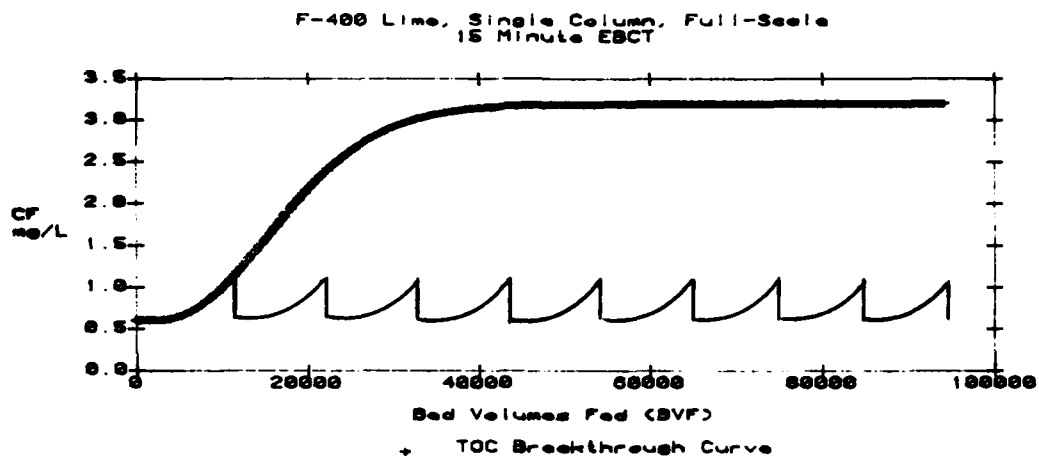
Figure 10.3-3(a) shows a typical breakthrough curve, in this case with an assumed EBCT of 15 minutes and with model parameters determined for lime treated water. The lower curve on this plot shows sequential regenerations if the lower treatment objective (T.O.) is used and if operation is such that the given objective is met by the single contactor.

Usage rates for parallel columns have also been calculated, with an assumption of 31 columns in parallel, as discussed later under "Preliminary Design Configuration". A typical breakthrough curve is shown in Figure 10.3-3(b), again for the case of a 15 minute EBCT for lime treated water. In this case, individual contactors were operated to higher effluent criteria, with the treatment objective being met on the average because of other contactors which are operating on the front of the breakthrough curve and are still producing relatively high quality effluent.

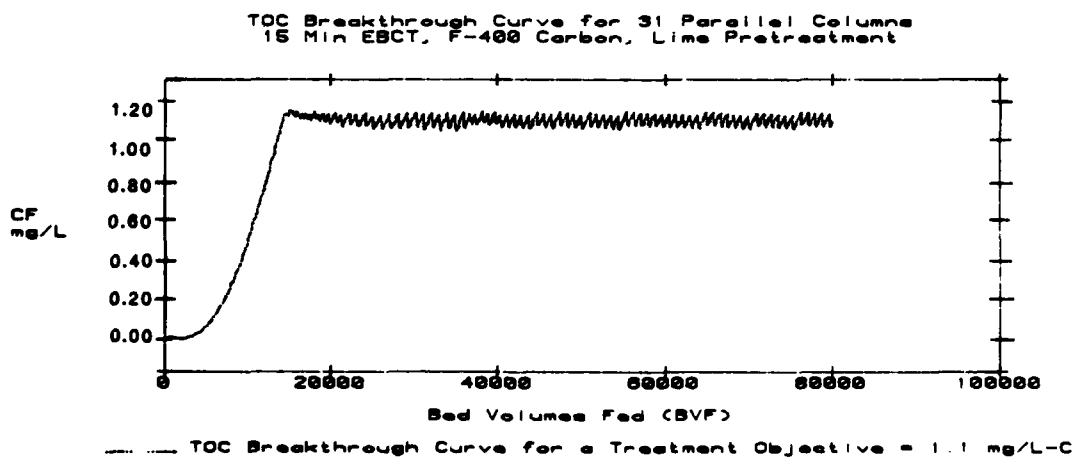
Usage rates were computed in this manner for single column and parallel operation to meet all three TOC treatment objectives and for EBCT ranging from 15 to 60 minutes. Results are shown in Figure 10.3-4. The regeneration criteria, based on single column effluent levels, is more stringent and thus more costly with higher usage rates as shown. For the same treatment objective, parallel operation and regeneration based on a blended effluent criteria reduces carbon usage significantly. Assuming parallel operation, usage rates are reduced to between forty percent (15 minute EBCT) and sixty percent (60 minute EBCT) of those calculated for a single contactor.

With respect to EBCT, Figure 10.3-4 shows that single contactor usage rates are significantly reduced at higher EBCTs, and particularly with more stringent treatment objectives. For parallel GAC contactors, however, longer EBCTs reduce the carbon usage only if stringent effluent treatment objectives are imposed. These potential savings must be compared to increased capital costs for longer EBCTs. As demonstrated in the cost section below, the longer EBCTs are not justified if parallel operation is utilized and the adsorbable TOC treatment objective is not more stringent than 0.5 mg/L-C.

**Preliminary Design Configuration.** Preliminary design of full-scale (200 MGD) GAC configurations were required in order to estimate capital costs for the various EBCT alternatives. Practical constraints on GAC designs were assessed based on information from operating GAC facilities, manufacturers of GAC systems, and published information (EPA, 1973, Culp and Faisst, 1981). Design was dictated by the following considerations:



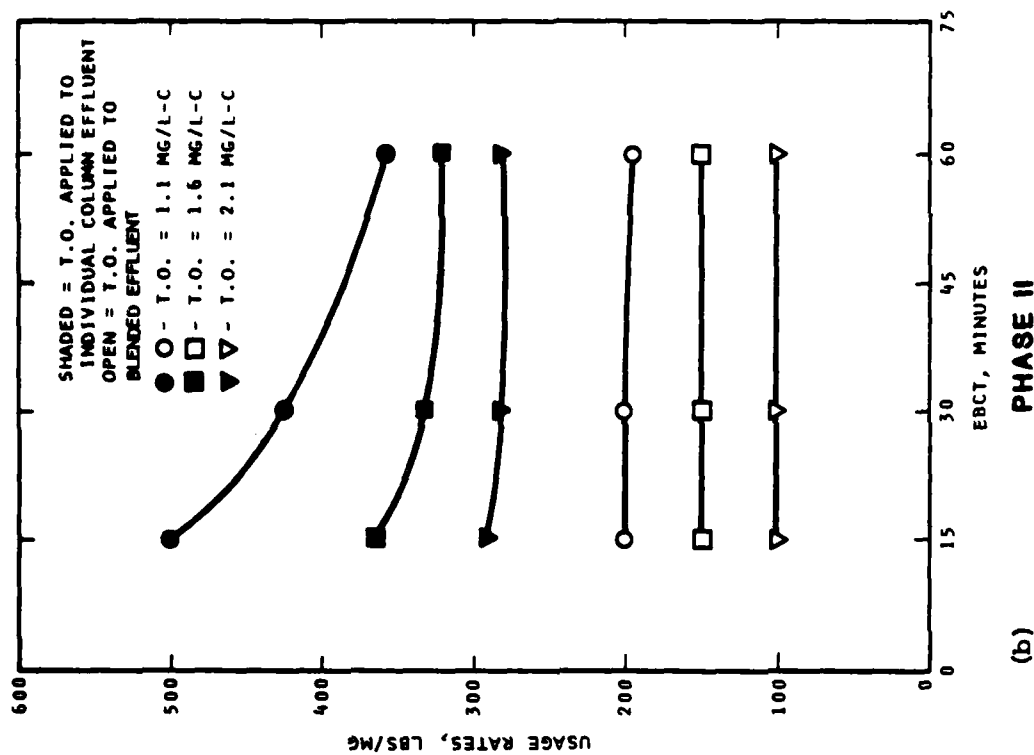
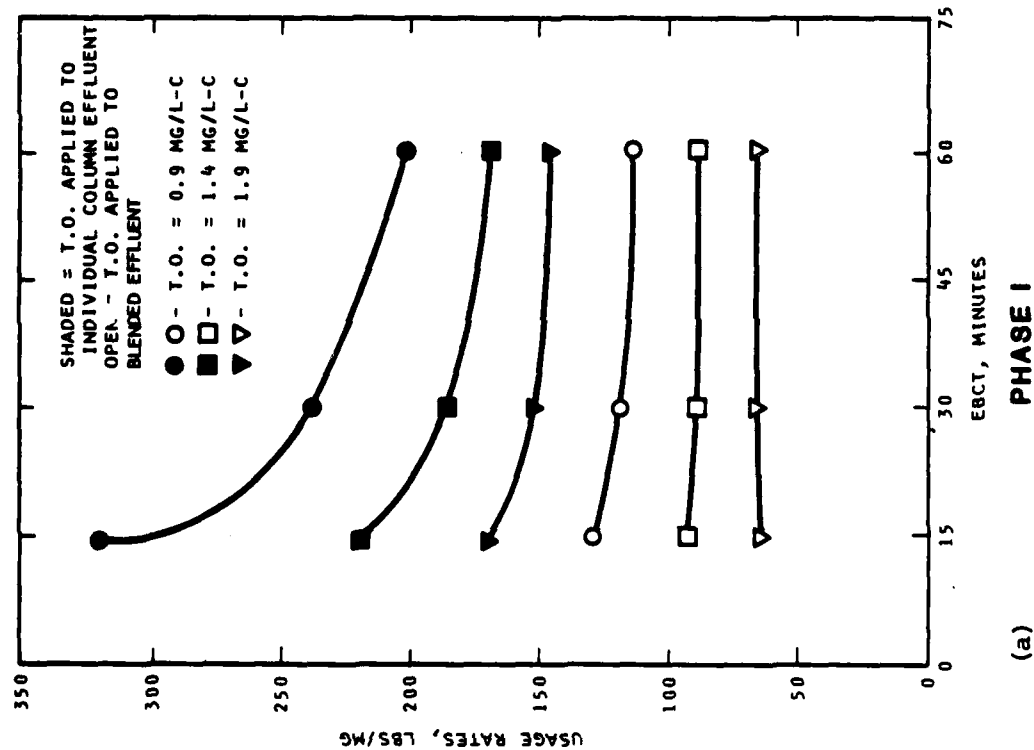
(a) Sawtooth shaped curve- single column operated never to exceed T.O.



(b) Parallel columns operated to continuously meet T.O.

## COLUMN BREAKTHROUGH CURVES FOR SINGLE AND PARALLEL COLUMN OPERATION (LIME PRETREATMENT)

FIGURE 10. 3-3



F-400 USAGE RATES  
INDIVIDUAL AND 31 PARALLEL COLUMNS  
FIGURE 10.3-4

## Investigations of Alternative Process Designs

1. Loading rate = 5 gpm/ft<sup>2</sup>, if practical. Loading rate should not be outside the range of 2 to 10 gpm/ft<sup>2</sup>.
2. Carbon Depth = 5 to 30 feet; 50 percent expansion during backwash.
3. Surface area/contactor  $\leq$  1000 ft<sup>2</sup>.
4. Two contactors in series.

The assumption of two contactors in series was made in order to more closely mimic the design incorporated at the EEWTP. This design also provides a more effective barrier against SOC's for any given TOC treatment objective, as fresher carbon is used in the "polishing" (lag) column.

Designs were assumed for both gravity GAC contactors of concrete construction and pressure contactors of steel construction. For both cases, columns approaching the maximum practicable surface area (1000 ft<sup>2</sup>) were utilized because of the large surface area requirements for a 200 MGD plant. The area/contactor assumed was 900 ft<sup>2</sup> in order to allow for 32 parallel contactor pairs in series (64 contactors) with one pair out of service and the remaining 31 loaded at 5 gpm/ft<sup>2</sup> to treat 200 MGD. This configuration allowed eight banks of four contactors each for symmetric distribution of flow. Each of the 64 contactors were assumed to meet the criteria shown in Table 10.3-5. Pressure contactors were designed for parallel or series operation, as shown in Figure 10.3-5. Gravity contactors were designed according to JMM standards for conventionally backwashed filter beds, with special provisions for parallel/series operation. For the latter, a design was assessed similar to that used at Andjik, Nord Holland, in the Netherlands; see Figure 10.3-6. As shown in the figure, contactors in banks A and B can serve as either lead or lag contactors, and may be interchanged by opening and closing the appropriate valves.

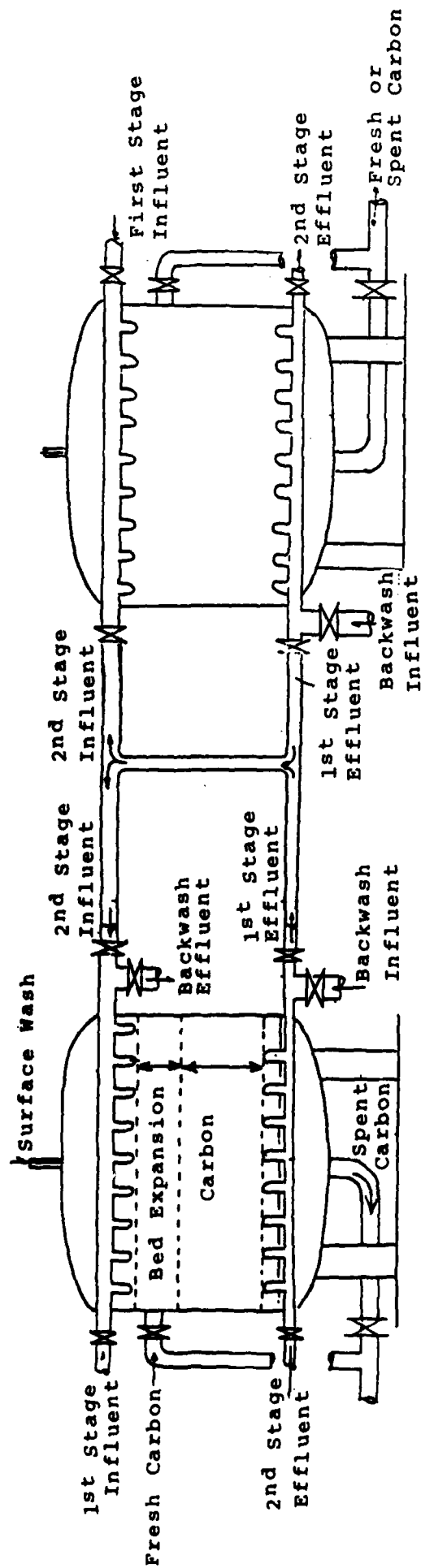
**Cost Estimates.** Preliminary design cost estimates were made for the alternative GAC design scenarios, as presented in Tables 10.3-6 and 10.3-7. for alum and lime pretreated water, respectively. These estimates were made using cost assumptions outlined in Chapter 11 and based upon preliminary engineering designs around the criteria previously discussed. Carbon usage rates used for regeneration costs were based upon parallel operation to a combined treatment objective, and are as previously shown in Figure 10.3-4.



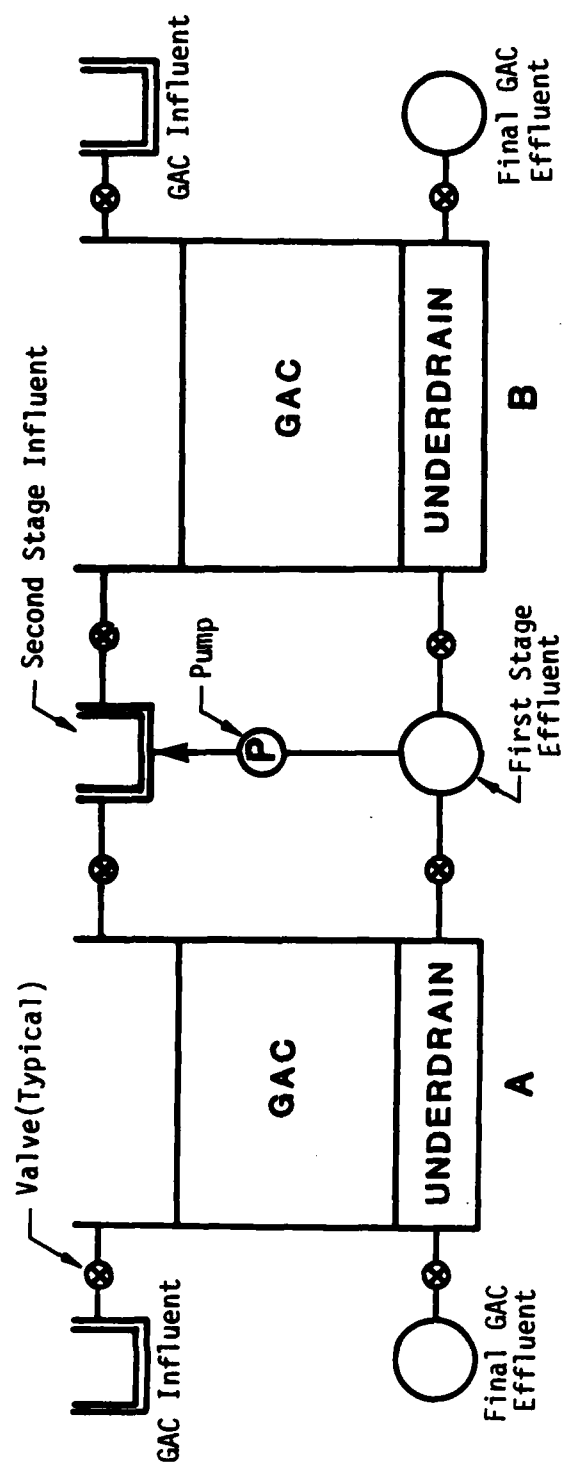
TABLE 10.3-5  
DESIGN PARAMETERS FOR TWO STAGE  
IN PARALLEL GAC OPERATIONS

EBCT min.	Surface Area m <sup>2</sup> (ft <sup>2</sup> )	Loading Rate l/sec-m <sup>2</sup> (gpm/ft <sup>2</sup> )	Carbon Depth m (ft)	Contactor <sup>a</sup> Depth m (ft)	Length m (ft)	Width m (ft)
<b>Gravity</b>						
15	62.8 (900) <sup>b</sup>	3.4 (5)	1.3 (5)	3.7 (14)	5.3 (20)	11.9 (45)
30	62.8 (900)	3.4 (5)	2.6 (10)	5.8 (22)	5.3 (20)	11.9 (45)
60	62.8 (900)	3.4 (5)	5.3 (20)	10.0 (38)	5.3 (20)	11.9 (45)
<b>Pressure</b>					<b>Diameter, m(ft)</b>	
15	62.8 (900)	3.4 (5)	1.3 (5)	3.7 (14)	9.0 (34)	
30	62.8 (900)	3.4 (5)	2.6 (10)	5.8 (22)	9.0 (34)	
60	62.8 (900)	3.4 (5)	5.3 (20)	10 (38)	9.0 (34)	

- a. Column Depth - Carbon depth + 50% expansion + 0.53 m (2 ft.) (Leopold Blocks & Gravel) + 0.26 m (1.5 ft.) (troughs) + 0.79 m (3 ft.) (freeboard).
- b. Large cross-sectional area used because of expected number of tanks, i.e., least cost anticipated to correspond to fewer, larger tanks.



TWO GAC PRESSURE CONTACTORS IN SERIES  
FIGURE 10. 3-5



SCHEMATIC OF SERIES CONFIGURATION  
FOR TWO GRAVITY GAC CONTACTORS  
ANDJIK, NORD HOLLAND, THE NETHERLANDS  
FIGURE 10. 3-6

# Investigations of Alternative Process Designs

TABLE 10.3-6  
ESTIMATED FULL SCALE COSTS FOR  
PARALLEL OPERATION  
(ALUM/POLYMER PRETREATED WATER)

Treatment Objective	Capital Costs Contactors and Auxiliary <sup>a</sup> (\$ Million)	Capital Costs Regeneration Facilities (\$ Million)	Annual O&M (\$ Million)	¢/1,000 gal (\$/100m <sup>3</sup> ) <sup>b</sup>
T.O.=0.9 mg/L				
15 min EBCT	28.0	5.1	3.4	9.5 (25.1)
30 min EBCT	40.3	4.9	3.2	11.0 (29.1)
60 min EBCT	59.5	4.8	3.1	13.6 (35.9)
T.O.=1.4 mg/L				
15 min EBCT	28.0	4.4	2.8	8.6 (22.7)
30 min EBCT	40.3	4.3	2.7	10.2 (26.9)
60 min EBCT	59.5	4.3	2.7	13.0 (34.3)
T.O.=1.9 mg/L				
15 min EBCT	28.0	3.7	2.4	7.9 (20.9)
30 min EBCT	40.3	3.7	2.4	9.7 (25.6)
60 min EBCT	59.5	3.7	2.4	12.5 (33.0)

- a. Assumes gravity contactors of concrete construction. (Estimated costs for pressure contactors were higher in all cases; see Appendix I.)
- b. April, 1983 dollars. Cost assumptions as discussed in Chapter 11, 20 years at 8%

TABLE 10.3-7

**ESTIMATED FULL SCALE COSTS FOR  
PARALLEL OPERATION  
(LIME PRETREATED WATER)**

<u>Treatment Objective</u>	<u>Capital Costs Contactors and Auxiliary<sup>a</sup> (\$ Million)</u>	<u>Capital Costs Regeneration Facilities (\$ Million)</u>	<u>Annual O&amp;M (\$ Million)</u>	<u>¢/1,000 gal (\$/100m<sup>3</sup>)<sup>b</sup></u>
T.O.=0.9 mg/L				
15 min EBCT	28.0	6.2	4.5	11.3 (29.9)
30 min EBCT	40.3	6.2	4.5	13.0 (34.3)
60 min EBCT	59.5	6.2	4.5	15.5 (40.9)
T.O.=1.4 mg/L				
15 min EBCT	28.0	5.4	3.8	10.2 (26.9)
30 min EBCT	40.3	5.3	3.7	11.8 (31.2)
60 min EBCT	59.5	5.3	3.7	14.5 (38.3)
T.O.=1.9 mg/L				
15 min EBCT	28.0	4.6	2.9	8.8 (23.3)
30 min EBCT	40.3	4.6	2.9	10.5 (27.7)
60 min EBCT	59.5	4.6	2.9	13.3 (35.1)

1. Assumes gravity contactors of concrete construction.
2. April, 1983 dollars. Cost basis as discussed in Chapter 11, 20 years at 8%.

**RECOMMENDATIONS**

The criteria for regeneration of GAC when treating a contaminated water source are still a subject of considerable debate. The EEWTP was operated with a single set of carbon contactors in series which were regenerated as discussed in Chapters 7 and 8. Larger scale facilities, however, will have many contactors operating in parallel. Because regeneration will, of necessity, be staged, it is likely that the levels of TOC in the blended effluent will generally be much less variable than observed for a single column as at the EEWTP.

Several potential TOC goals were considered for this project. The alternative goals, and associated design recommendations, are discussed in the conclusions listed below.

1. Operation of single contactors to the treatment objectives implied by EEWTP operation is assumed for the cost estimates of Chapter 11. These estimates are based on actual plant usage rates during Phases IA and IIA. Average TOC in GAC effluent during these two phases was 1.6 and 1.2 mg/L TOC, respectively. If, in fact, the regeneration criteria were to be

## Investigations of Alternative Process Designs

based on single column effluent, Figure 10.3-4 suggests that longer empty bed contact times would lead to potential cost savings.

2. Each TOC goal was more efficiently met through parallel column operation with individual columns on line for longer periods of time and the carbon more effectively utilized.
3. If parallel operation is utilized, a longer EBCT is not required to achieve effective carbon usage, and reductions in operational cost are minor. The higher capital costs of longer EBCT make them not cost effective. The optimum EBCT for TOC removal for a treatment criteria of 1.0 mg/L was not determined but is shown to be below 15 minutes, see Figure 10.3-4. Contact times of less than 15 minutes were never demonstrated with respect to their ability to protect against SOC breakthrough, however, and cannot be recommended.
4. Pilot spiking studies with PCE indicate that a fifteen minute EBCT in a contactor exhausted with respect to TOC may still have considerable capacity for adsorbable SOCs, given an influent water quality similar to that at the EEWTP.
5. GAC costs for reaching specific steady-state TOC concentrations are as shown in Tables 10.3-6 and 10.3-7. For all treatment objectives examined, a contact time of 15 minutes is recommended.
6. Two stage series operation is recommended for added protection against SOC breakthrough. The loading rate utilized at the EEWTP was 5 gpm/ft<sup>2</sup> and is recommended for a full-scale 200 MGD design. Thirty-two parallel sets of gravity contactors are recommended, with each filter at 900 ft<sup>2</sup> as outlined in Table 10.3-5.
7. Selection of the design criteria for carbon regeneration based on a specific TOC treatment objective is difficult, because TOC levels do not correlate with potential health effects to consumers. Selection of the lowest TOC value would be conservative and would provide the greatest degree of protection to consumers, but at an increase in cost.

Because of the contaminated source, it is recommended that a regeneration criterion of 1 mg/L TOC (the lowest criterion evaluated) be assumed when considering the blended effluent from many columns operated in parallel. GAC operating costs with this criteria are still lower than those generated on the basis of the EEWTP single column experience, as discussed in Chapter 11.

## PACKED TOWER AERATION

### BACKGROUND AND APPROACH

As previously discussed, the potential contamination of an estuary water supply with synthetic organic chemicals represents a source of serious concern with respect to health effect. Of the SOCs currently identified in wastewaters and

water supplies, many are relatively volatile and removal may be achieved through aeration. Where feasible, aeration is generally cost-effective, particularly when compared with adsorption processes, such as treatment with granular activated carbon.

Aeration processes which have been applied to the removal of volatile organic chemicals (VOCs) include diffused aeration, surface aeration, spray aeration, and counter-current packed tower aeration. Of the available aeration processes, counter-current packed tower aeration offers the advantage of cost-effective designs when removals greater than ninety percent are required.

In addition to its low cost, other principle attributes of packed tower aeration are its simple design and operation. Typically, an air stripping tower would consist of a Fiberglas (RFP), steel, or concrete tank filled with a plastic packing material. A centrifugal fan is used to move air up and through the packing while the water to be treated trickles down and is collected in a plenum at the base of the tower. VOCs are transferred from the liquid phase to the air as the water passes through the tower.

Packed tower aeration is a potential process for consideration for a full scale estuary treatment plant. Air stripping would provide an effective barrier against volatile SOC's, and during a spill situation, could prevent breakthrough of these compounds in downstream processes. Used in conjunction with activated carbon, for example, a preceding air stripping process would prevent high concentrations of VOCs from entering the GAC columns thus preventing the accumulation of these compounds for potential subsequent breakthrough and/or desorption.

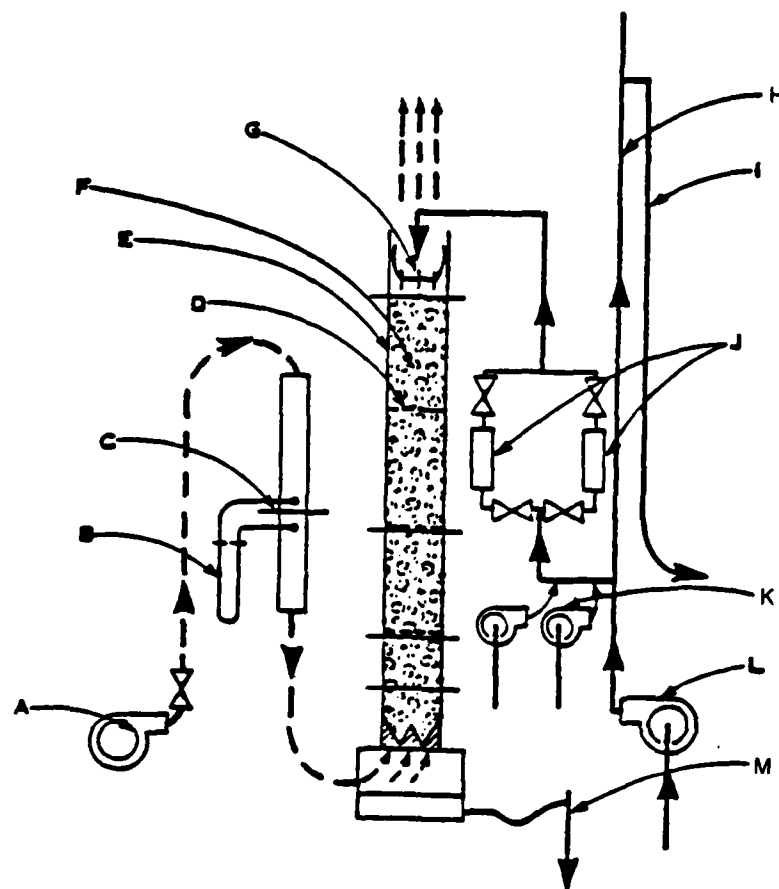
### Pilot Work

In order to determine optimum design criteria for packed tower aeration, specific information was required with respect to the rates of mass transfer for the compounds in question. Using a 20 to 380 m<sup>3</sup>/d (2 to 35 gpm) pilot scale air stripping unit, shown in Figure 10.3-7, mass transfer coefficients for five VOCs were evaluated for a selected plastic packing material<sup>1</sup> over a range of air and liquid loading rates.

Pilot runs were conducted at four different tower heights in order to determine the impact of tower end effects on removal performance and thus permit an accurate determination of required tower height. Mass transfer coefficients for the five compounds were determined at each run condition. These were then correlated to liquid loading rate, based on a linear regression of an appropriate correlation from the chemical engineering literature. This allowed considerations of design alternatives beyond the specific cases which were directly tested.

---

1. 1" Super Intalox Saddles (Norton Co.)



- A - Fan, 0-300 cfm
- B - Inclined Manometer
- C - 10 inch Flange Orifice air Flow Meter
- D - Redistributor
- E - 12 inch Diameter, Plexiglass Tower Shell
- F - Packing
- G - Water Distributor
- H - 14 ft. Standpipe
- I - Standpipe Overflow to Waste
- J - 0-6 and 5 to 40 gpm Rotameters
- K - Chemical Feed Pumps, Tygon tubing
- L - Influent Water Pump 40 gpm
- M - Adjustable Height Tower Effluent Overflow

**PILOT AERATION TOWER SCHEMATIC**  
**FIGURE 10. 3-7**



## Investigations of Alternative Process Designs

The pilot tests described above were conducted by spiking an alcohol based solution of the five compounds ( $\text{CHCl}_3$ ,  $\text{CCl}_4$ , PCE, TCE, and bromoform) to the pilot air strippers influent, which was a sidestream of EEWTP gravity filter effluent during Phase IA. A full description of the pilot equipment, methods, and run conditions examined is provided in Appendix I.

### Evaluation of Design Alternatives

Design alternatives for this project were determined through the use of a computerized version of an air stripping design model, which has been well documented in the chemical engineering literature and recently applied to drinking water applications. For removal of a specific compound, the design model relates the required height of an air stripping tower to liquid and gas loading rates according to the following relationship:

$$Z = \left[ \frac{L}{(K_L a) C_o} \right] \left[ \frac{1}{1 - \frac{P_t L}{HG}} \right] \ln \left[ C_{in}/C_{out} \left( 1 - \frac{P_t L}{HG} \right) + \frac{P_t L}{HG} \right] \quad (1)$$

where:

Z is packing height (m)

H is the Henry's constant for the compound to be removed (atm)

$P_t$  is the ambient pressure (atm)

L is the liquid loading rate ( $\text{kmole/sec/m}^2$ )

G is the air loading rate ( $\text{kmole/sec/m}^2$ )

$K_L a$  is the product of the overall liquid mass transfer coefficient,  $K_L$  (m/sec), and the specific interfacial area,  $a$  ( $\text{m}^2/\text{m}^3$ ), in the packing system

$C_o$  is the molar density of water ( $55.6 \text{ kmole/m}^3$  at  $20^\circ\text{C}$ )

$C_{in}$  is the influent concentration of the compound to be removed (units of concentration)

$C_{out}$  is the effluent concentration of the compound to be removed (units of concentration)

The above relationship may be rewritten as

$$Z = (\text{HTU}) (\text{NTU})$$

$$\text{with HTU} = \frac{L}{K_L a C_o}$$

and NTU may be given by:

$$\text{NTU} = \frac{R}{R-1} \ln \frac{C_{in}/C_{out} (R-1) + 1}{R}$$

$$\text{with } R = \frac{HG}{P_t L}$$

HTU, NTU and R are defined as the "height of a transfer unit," the "number of transfer units", and the "stripping factor," respectively. A more complete description of the relationships in equation (1) is provided in Appendix I.

## Investigations of Alternative Process Designs

For a given compound and treatment requirement, design scenarios were examined by determining the required packing depth for a range of liquid and gas loading rates. These reflect selections of pressure drop (or tower diameter) and air-to-liquid rates, respectively. All other parameters in equation (1) are known, with compound volatility (H) taken from the literature and  $K_L a$  for the given compound and packing determined from pilot results, as discussed above. Based on computer generated capital and operating costs, the optimum design was then determined for the given treatment requirements.

In order to generate a conservative design for air stripping in an estuary treatment plant, tower requirements were set at a 300 to 1 reduction of  $\text{CHCl}_3$ , or 96.6 percent removal. The resulting design would achieve equivalent or better removals of three VOCs judged to be of special concern and similarly modeled. These were carbon tetrachloride ( $\text{CCl}_4$ ), tetrachloroethene (PCE), and trichloroethene (TCE), compounds more volatile than  $\text{CHCl}_3$  (see Table 10.3-8). Although other VOCs were not specifically modeled, it can be anticipated that removal of most compounds of equal or higher volatility than chloroform would be at least 95 percent. Henry's constants for the five compounds studied in the EEWTP pilot work are shown in Table 10.3-8.

TABLE 10.3-8  
HENRY'S CONSTANTS AS A FUNCTION OF TEMPERATURE  
FOR SPECIFIC VOCs

Compound	H at 20°C (atm)	Assumed Temperature Correlation <sup>1</sup> (T = temperature, °K)
Carbon Tetrachloride $\text{CCl}_4^2$	1280	$\text{Log}(H) = \frac{-2038}{T} + 10.06$
Tetrachloroethylene PCE <sup>2</sup>	1040	$\text{Log}(H) = \frac{-2159}{T} + 10.38$
Trichloroethylene TCE <sup>2</sup>	540	$\text{Log}(H) = \frac{-1716}{T} + 8.59$
Chloroform $\text{CHCl}_3^2$	170	$\text{Log}(H) = \frac{-2013}{T} + 9.10$
Bromoform $\text{CHBr}_3^3$	50	$\text{Log}(H) = \frac{-3607}{T} + 14.0$

1.  $\text{Log}(H) = \frac{-\Delta H^\circ}{RT} + k$  where R = universal gas constant,  $1.987 \frac{\text{kcal}}{\text{kmol-}^\circ\text{K}}$ ; T = absolute temperature, °K;  $\Delta H^\circ$  = change in enthalpy due to dissolution of compound in water (kcal/kmole); and k = constant.
2. Correlations as reported by Kavanaugh and Trussell (1980, 1981).
3. Correlation adopted from graphical results presented by Selleck, et al (1981).

## DISCUSSION OF RESULTS

### Pilot Results

Table 10.3-9 presents the mass transfer coefficients as determined from pilot runs at different loading rates and tower heights. All results have been normalized to a temperature of 20°C. The regression coefficients in Table 10.3-9 relate the plots of NTU versus packing depth, as discussed in Appendix I. The slopes of such plots were utilized in determining  $K_L a$  and the associated confidence limits.

As can be seen from Table 10.3-9, confidence limits are generally quite good, although the results for bromoform are less than satisfactory. This is further illustrated in Figure 10.3-8, which presents the correlation of mass transfer coefficient to liquid loading rate, based on an empirical correlation from the chemical engineering literature. The reader is referred to Appendix I for a discussion of this correlation and potential explanations of the poor fit to bromoform results. Essentially, the lower volatility of bromoform impact the results in two ways: (1) experimental results are much more sensitive to the assumed value of  $H$ , and (2) the gas phase mass transfer, not considered in the correlation of Figure 10.3-8, is much more important. Although the gas transfer resistance could be incorporated into the design model, this was not done for this study and bromoform removal was not evaluated for designs other than those specifically piloted.

### Design Evaluations

For the four compounds which showed a good correlation of  $K_L a$  to liquid loading rate, it was possible to extrapolate the pilot scale results to a variety of potential design scenarios in order to determine removal efficiency and cost. As previously noted, a specific treatment goal of 97 percent chloroform removal was selected for evaluation of potential full scale designs. This arbitrary requirement was selected as a reasonable criteria for ensuring significant removal of VOCs more volatile than  $\text{CHCl}_3$ .

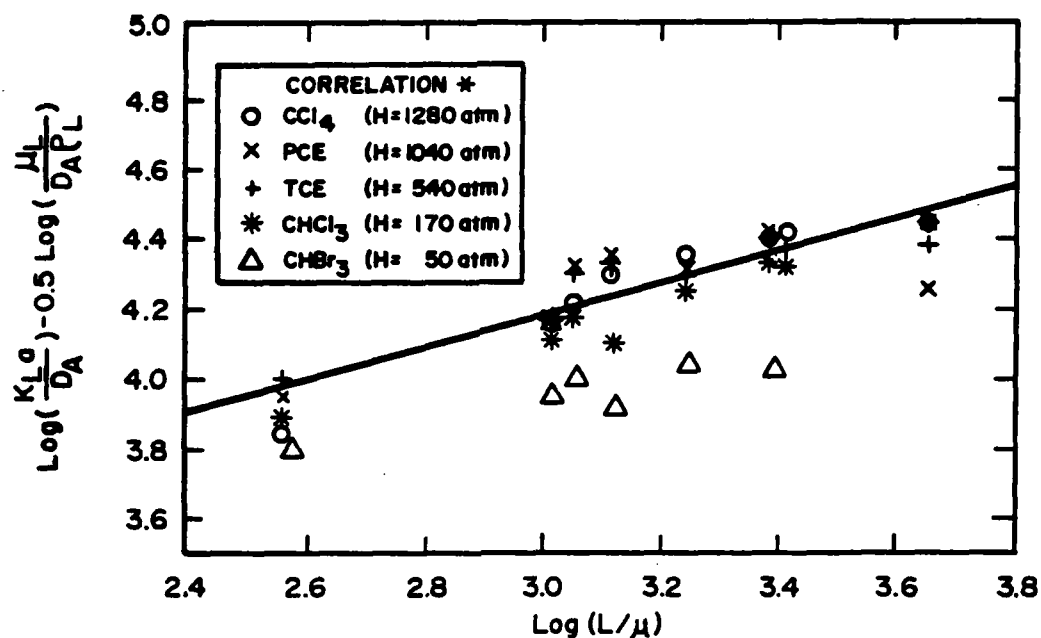
Figure 10.3-9 presents the results of computer cost modeling for the given treatment requirement. In this figure costs are shown as a function of air to liquid ratio (as defined by the stripping factor,  $R$ ) and air pressure drop through the tower. The least cost alternative occurs at low pressure drops of about 25 to 50  $\text{N/m}^2\text{-m}$  (0.03 to 0.06 inches of water) and at a stripping factor for chloroform of about 5. The latter corresponds to an air to liquid ratio (volume:volume) of about 40:1. It should be noted that the costs shown in Figure 10.3-9 are for the stripping tower, tower internals, packing material, pump, and blower costs only. Auxiliary equipment, instrumentation, earth work, and influent or effluent clearwell costs are not included. The design criteria for this optimum design are provided in Table 10.3-10, as are the anticipated removals for the four modeled compounds.

It must be noted that the projected removals in Table 10.3-10 do not include any factor of safety and are for an influent water temperature of 20°C. At cooler temperatures, the removal efficiency of air stripping decreases due to

# Investigations of Alternative Process Designs

TABLE 10.3-9  
PILOT DETERMINATIONS OF  $K_L a$

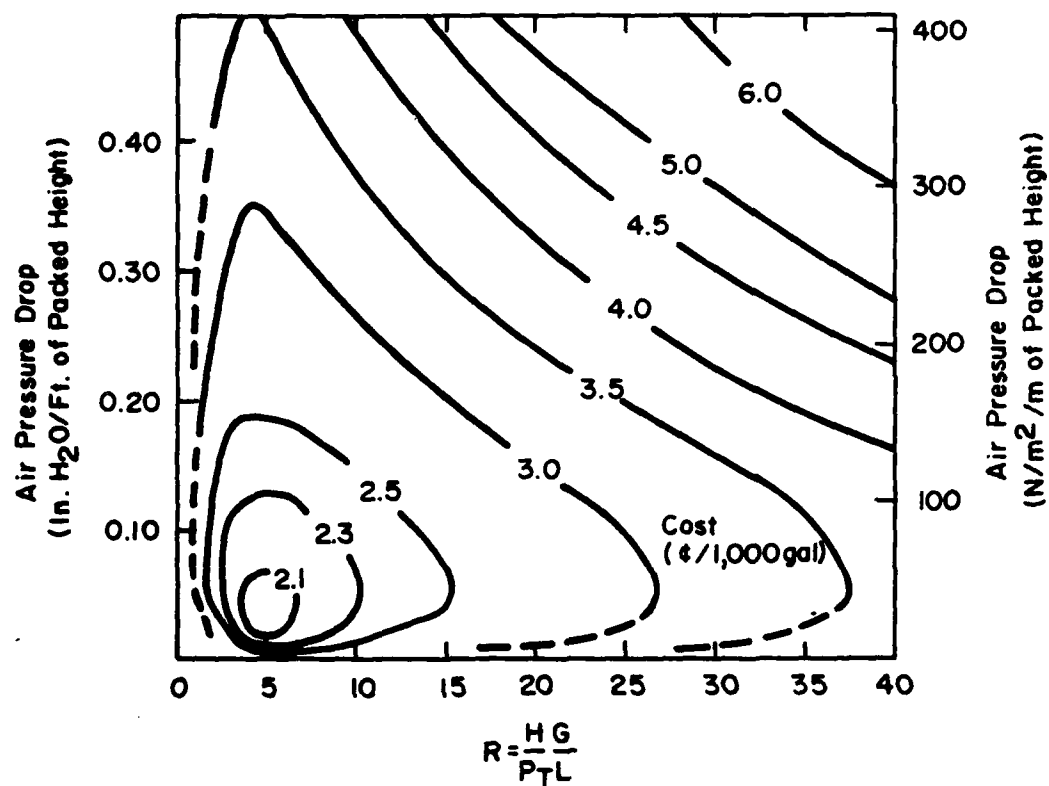
Run Conditions		Mass Transfer Results - Plot of NTU versus Depth							
		CCl <sub>4</sub>		PCE		TCE		CHCl <sub>3</sub>	
$\frac{1}{L}$ L/m <sup>2</sup> sec (gpm/sf)	$\frac{Q}{L}$ L/m <sup>2</sup> sec (cfm/sf)	Mult-R Regression Coeff.	$K_L a$ +90% Conf. Region hr <sup>-1</sup>	Mult-R Regression Coeff.	$K_L a$ +90% Conf. Region hr <sup>-1</sup>	Mult-R Regression Coeff.	$K_L a$ +90% Conf. Region hr <sup>-1</sup>	Mult-R Regression Coeff.	$K_L a$ +90% Conf. Region hr <sup>-1</sup>
1.2 (1.8)	655 (129)	0.944	8.26 +1.33	0.999	10.5 +0.8	0.99997	11.4 +0.1	0.992	9.04 +1.67
3.4 (5.0)	513 (101)	0.913	16.5 +10.5	0.930	16.2 +9.2	0.946	16.9 +8.3	0.956	15.7 +6.7
3.7 (5.5)	655 (129)	0.974	18.9 +3.2	0.986	20.8 +2.5	0.987	20.8 +2.4	0.969	18.9 +3.4
4.3 (6.4)	655 (129)	0.995	22.4 +3.2	0.982	24.5 +6.8	0.991	24.2 +4.8	0.995	15.4 +2.3
5.8 (8.5)	868 (171)	0.997	25.4 +2.9	0.994	23.0 +3.7	0.991	23.2 +4.5	0.988	21.5 +4.8
8.1 (11.9)	1219 (240)	0.911	28.8 +18.6	0.933	28.7 +15.8	0.927	28.8 +16.7	0.866	26.5 +21.5
8.5 (12.5)	655 (129)	0.739	29.3 +36.0	0.716	27.0 +35.1	0.740	27.6 +33.8	0.649	26.0 +39.5
14.9 (21.9)	655 (129)	0.961	30.9 +12.8	0.934	29.5 +16.2	0.939	27.5 +14.4	0.888	21.3 +15.6
								0.601	-18.5 +31.1



**PILOT DATA FOR ALL COMPOUNDS FITTED TO  
SHERWOOD-HOLLAWAY CORRELATION**

**(alpha = 696, n = 0.55)**

**FIGURE 10. 3-8**



**RELATIVE COST (\$/1000 Gal)**  
**CHLOROFORM,  $X_1/X_0 = 30$  ( $T = 20^\circ \text{C}$ )**

**FIGURE 10. 3-9**

TABLE 10.3-10  
DESIGN CRITERIA AND COST ESTIMATE FOR  
200 MGD PACKED TOWER AERATION<sup>1</sup>

Design Criteria

Packing material:	1-inch plastic Super Intalox saddles	
Liquid flow rate:	8.8 m <sup>3</sup> /sec	(200 MGD)
Gas flow rate:	340 m <sup>3</sup> /sec	(723,000 cfm)
No. of towers	2	
Tower diameter	21.6 m	(71 ft)
Depth of packing	5.3 m	(17.5 ft)
Volume of packing	3,700 m <sup>3</sup>	(140,000 ft <sup>3</sup> )
Estimated air pressure drop through packing dome	270 NT/m <sup>2</sup>	(1.1 inches of water)

Calculated Removals (at 20°C)

CCl <sub>4</sub>	97.5%
PCE	97.1%
TCE	97.4%
CHCl <sub>3</sub>	96.6%

Estimated Costs (1983) dollars)

Capital cost of tower and internals, pumps and blowers:	\$7,250,000
Other capital costs <sup>2</sup> :	1,400,000
Total capital cost:	\$8,650,000
Total construction cost <sup>3</sup> :	\$11,940,000
Power costs (@ \$0.07/kw-hr)	\$ 690,000/yr
Other O&M costs <sup>4</sup> :	130,000/yr
Total operational costs:	\$ 820,000/yr

- 1 Optimum design for 200 MGD process assuming use of 1-inch Super Intalox saddles; treatment objective of 96.6 percent chloroform removal at 20°C; cost assumptions for optimization as discussed in text.
2. Effluent clearwell, valving, piping, instrumentation and all associated site-work, earthwork and foundation costs, including 15 percent contingency.
3. Includes contractor overhead and profit, engineering, legal, fiscal and administrative costs, and interest during construction. Costs in 1983 dollars.
4. Assumes 20 hours/week operation and maintenance time at \$15/hour plus 10 percent of mechanical equipment costs (pumps and blowers) per year.

reductions in volatility and transfer. At a hypothetical influent temperature of 6°C, removal of chloroform is calculated to be 90.5 percent.

## RECOMMENDATIONS

The results from pilot work conducted during this project confirmed that air stripping for removal of VOCs is a feasible and potentially cost-effective process. Air stripping would provide an effective barrier against all six of the VOCs currently being considered for regulation (see Chapters 1 and 9). Treatment costs, as estimated for key process components in the previous section, appear to be quite reasonable. With respect to application in a full scale estuary plant, air stripping has the additional advantage of being extremely easy to start-up on short notice, with minimal difficulty associated with long periods of shut down and/or by-pass.

It is recommended that packed tower aeration be considered as a potential process alternative for a full scale estuary plant. Because of continuing concern for SOC's of unknown composition, however, it is not recommended that air stripping be considered for use without a second barrier for SOC's in the treatment train. Granular activated carbon and/or reverse osmosis are the two additional unit processes which have received the most attention for SOC removal in drinking water applications, and have both been considered for this project. Air stripping in conjunction with either of the processes would provide a dual barrier for the large majority of identified SOC. Such process trains offer reduced risk for SOC breakthrough and potentially improved water quality. Cost implications of these alternative process combinations are considered in Chapter 11 of this report.

Although the capital and operating costs of air stripping are relatively straight forward to determine, the impact of the process on downstream process operating costs is difficult to assess. With no advance information as to the potential for spills or other sources of high SOC concentrations in influent water, for example, carbon regeneration can only be assumed on the basis of TOC or other surrogate parameters (see previous section of this chapter). In this context, air stripping offers no operational cost savings and can only be considered as additional capital expense for added protection. If one assumes that the process would not be operated except in situations where it would be beneficial, then the most appropriate method of estimating costs is to consider only the added capital expense with no adjustment to overall operational costs. The implication is that the process would not be operated except during emergency situations under which otherwise added costs of downstream process operation would more than pay for operating the packed tower. This implies frequent monitoring of plant influent for SOC's, which would always be recommended for a plant of this nature in any case.

In summary, air stripping is recommended for further consideration as a second barrier for protection against volatile SOC's, and its capital cost estimated for potential inclusion with a process train, based upon 97 percent removal of chloroform, a moderately volatile compound. Because of uncertainties with respect to influent water quality, however, no reductions or additions to overall plant operating costs can be reasonably determined.



## REVERSE OSMOSIS

### BACKGROUND AND APPROACH

The reverse osmosis (RO) water treatment process utilizes a semi-permeable membrane to remove dissolved solids from water solutions. The basic theory of the process is that water under high pressure will pass through the membrane more rapidly than dissolved solids. A brine containing the rejected dissolved solids exits from the RO module and is either discarded or further treated in a subsequent module. A more complete description of the process and related theory are provided in Appendix I.

Reverse osmosis is most typically utilized for removal of inorganic salts which cannot be removed by more conventional processes. Typical applications involve the use of RO for obtaining drinking water from sources which would otherwise be too saline for beneficial consumption and use. The process was installed at the EEWTP as a 0.44 L/s (7 gpm) sidestream. It offers potential process advantages which warrant its consideration as an alternative process for design, as listed below.

1. Certain inorganic parameters, most notably nitrate and sodium, were found in higher concentrations in EEWTP finished water than in that from local treatment plants in the MWA. Both parameters were relatively unaffected by the plant-scale treatment processes. Although there are mitigating circumstances related to the appropriate level of concern for these parameters (see Chapter 9), each is of significance with respect to public health. Investigation of an alternative process capable of achieving this removal, such as RO, was warranted.
2. There is some potential that revised assumptions and/or modified water quality modeling will project higher levels of total dissolved solids than those modeled during this project. Preliminary data from studies conducted with the U.S. Corps of Engineers Chesapeake Bay Model indicate that this may be the case. If TDS levels in the estuary are above 500 mg/L (the federal secondary MCL) by significant amounts or for long duration, it is likely that some form of TDS removal will be required on at least a portion of the plant flow. RO is capable of providing this removal.
3. The reverse osmosis process also offers a potential removal of other inorganic parameters of concern (such as heavy metals), as well as of organic compounds. In this regard, reverse osmosis might be considered as a potential organic barrier to be used in conjunction with granular activated carbon or packed tower aeration. The potential for reverse osmosis as a substitute for granular activated carbon in these respects merits consideration.

In order to answer some of the questions associated with these issues, the reverse osmosis sidestream at the EEWTP was operated over a two and one half month period at the end of Phase II operation. The process was operated on gravity filter effluent, as discussed in Appendix I.

## Investigations of Alternative Process Designs

A schematic of the RO system used in the EEWTP is shown in Figure 10.3-10. The membranes were polyamide type (Dupont, B-9) in a wound hollow fiber configuration, with a rated operating pressure of 400 psig, and temperature and pH operational ranges of 0 to 35°C, and 4 to 11, respectively. The polyamide membranes are known to have high chemical and physical stability conducive to long operational lifetime.

The gravity filter effluent from the EEWTP was prefiltered through a 10  $\mu$ m cartridge filter. To minimize precipitation of insoluble solids and clogging of the membranes, the process was operated at a pH of 6, and a chelating agent, sodium hexametaphosphate, was added to the RO influent at a concentration between 5 and 10 mg/L.

The selected operating pressure was 350 psig, chosen to produce satisfactory rejection of the problem ions, sodium and nitrate in a three-stage process configuration. The operating pressure was nearly 100 times greater than the estimated osmotic pressure of the influent water with a TDS value (geometric mean) of 337 mg/L.

The sampling and analytical program are discussed in Appendix I, Section 5.

### DISCUSSION OF RESULTS

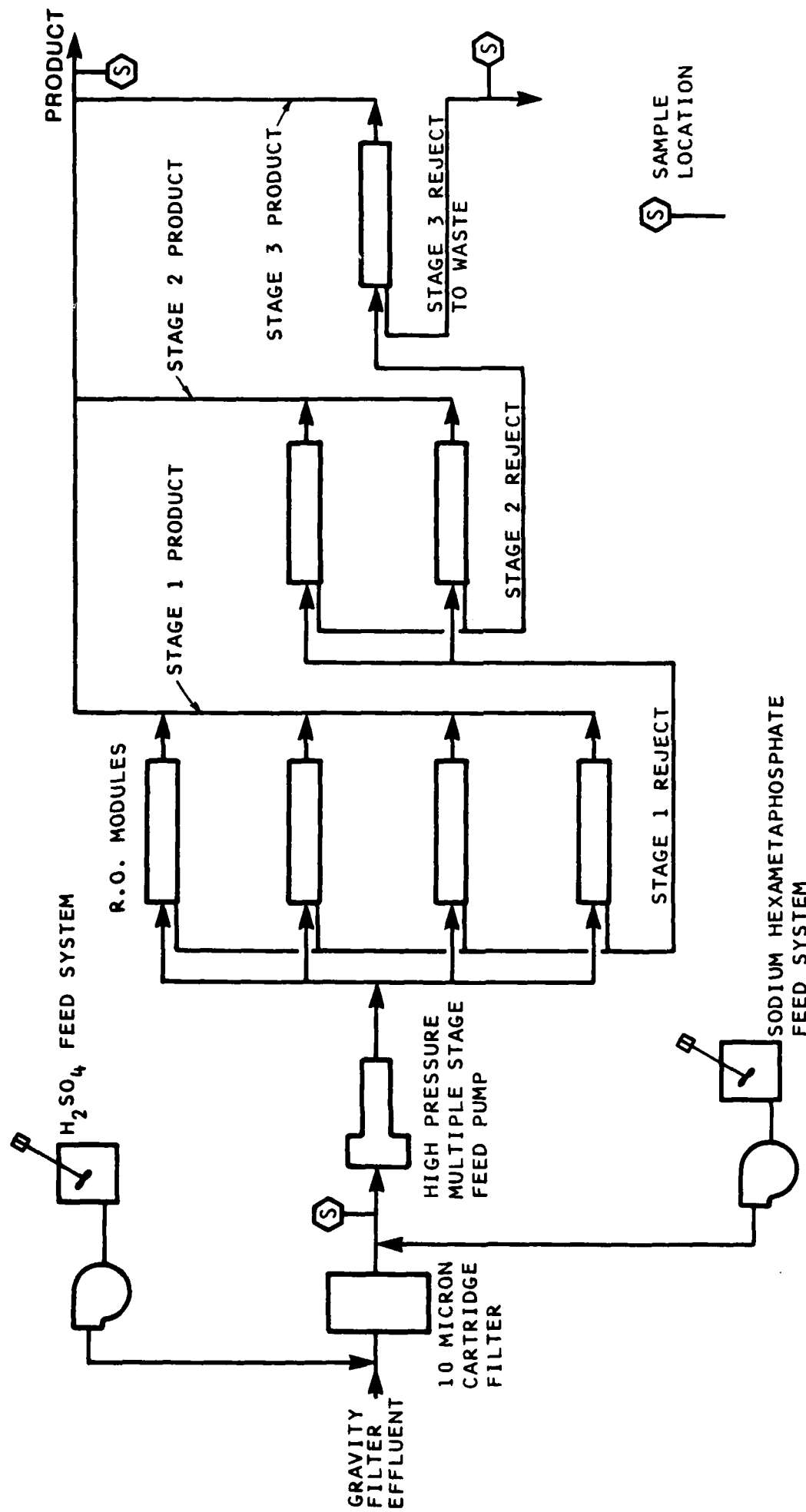
During the eighty day operational period, the influent water temperature varied from a high of 14°C to a low of 2.7°C. The percent recovery, defined as the percent of influent treated to finished quality, matched the fluctuation in the influent water temperature, decreasing as temperature fell and increasing as it rose. The percent recovery ranged from 76 percent to 68 percent, decreasing about 7.3 percent every 10°C.

The test was not of sufficient duration to evaluate clogging problems due to bacterial or inorganic deposits on the membrane surface. This phenomenon can severely increase the cost of RO membranes, due to shortened operational life.

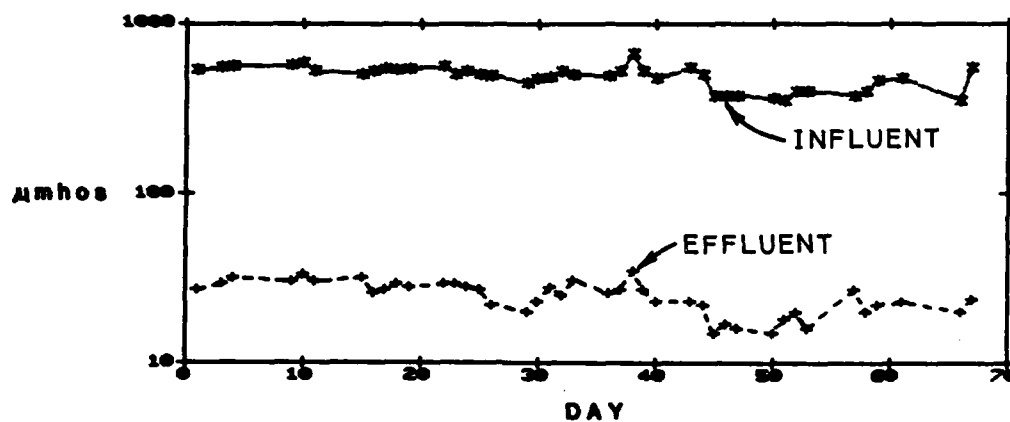
The RO process was quite effective in removing most inorganic parameters, higher molecular weight organic compounds (as characterized by TOC), and bacteria as characterized by the Standard Plate Count. Worse removals were observed for ammonia, and lower molecular weight volatile organic chemicals, including the trihalomethanes. The results are briefly summarized below by parameter group. See Appendix I, Section 5 for a more detailed discussion of RO performance.

#### Major Cations, Anions, Nutrients

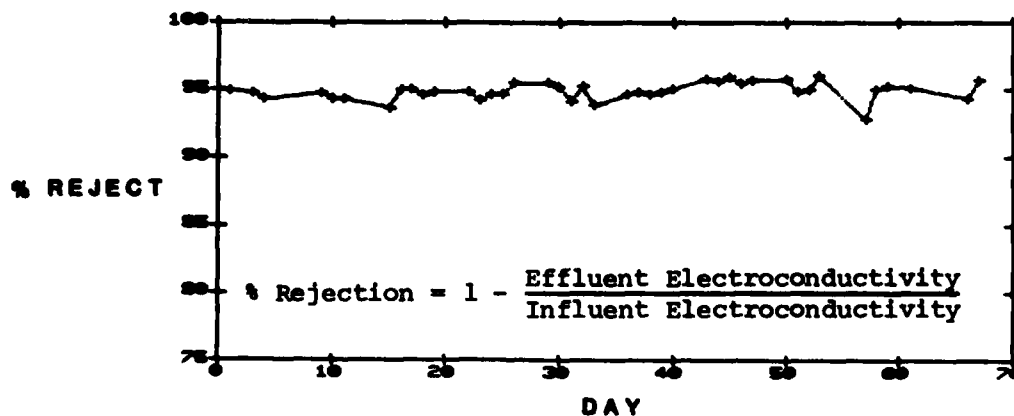
As expected, the polyamide membranes effectively reduced the levels of most parameters in this group. Figure 10.3-11 shows a time-series plot of the RO influent and effluent electroconductivity over the duration of the test period. Correspondingly, the total dissolved solids were reduced from 337 mg/L to 4.7 mg/L, based on geometric values, or a 98.6 percent removal.



**REVERSE OSMOSIS SYSTEM**  
**FIGURE 10. 3-10**



**ELECTROCONDUCTIVITY IN  
REVERSE OSMOSIS FEED AND PRODUCT  
FIGURE 10. 3-11**



**ELECTROCONDUCTIVITY - % REJECTION  
FIGURE 10. 3-12**

## Investigations of Alternative Process Designs

The observed removals for several key parameters are shown in Table 10.3-11. Of the anions, chloride and sulfate levels were reduced below the method detection limits (MDL). Rejection of the major cations was generally greater than ninety percent as shown in Figure 10.3-12. Sodium, a parameter of health significance, was reduced well below the EPA recommended level of 20 mg/L as seen in Table 10.3-11.

The membranes were also very effective in removal of nitrate ion, exhibiting over 97 percent removal of this key parameter of known health significance. The geometric mean value in the produce water was 0.1 mg/L-N, reduced from 5.6 mg/L-N in the RO influent.

On the other hand, very erratic results were observed for ammonia removal, with the results showing an apparent increase in  $\text{NH}_3$  levels across the membranes. The results indicate that the membrane is not effective for removing ammonia nitrogen but effectively removes nitrate. Total kjeldahl nitrogen (TKN) was reduced by fifty percent. Because of the uncertainty in the ammonia results, however, the degree of removal of organic nitrogen was also uncertain.

**Trace Metals.** A summary of trace metals removals is shown in Table 10.3-12. Observed reductions in metals concentrations (geometric means) ranged from a low of sixty percent for iron up to complete removal (below MDL) for barium chromium, manganese, nickel, and vanadium. Clearly, the RO process would be an effective barrier for control of trace metal contaminants.

### Trace Organics

The organic parameters monitored include the two surrogate parameters, TOC and TOX, and organic chemicals analyzed by the liquid-liquid extraction technique.

Total organic carbon removals averaged approximately eighty percent with a mean value of 0.6 mg/L-C in the product water. TOX levels were reduced below the detection limit of 3.9  $\mu\text{g/L-Cl}$ . Thus, the membranes are quite effective in removing organic compounds of high molecular weight (greater than about 200). For low molecular weight volatile organic compounds such as the trihalomethanes, PCE and TCE, lower removals were observed as summarized in Table 10.3-13.

Several THM formation tests were run on the RO feed water and the product water. Removals of seven-day THMFP (97 percent) were greater than the percent removals of TOC (approximately 80 percent) suggesting that the RO process may have preferentially removed precursors of THM formation.

**Microbiological Parameters.** Standard plate count analyses were conducted on a routine bases during the test period, using daily grab samples. Removals

## Investigations of Alternative Process Designs

TABLE 10.3-11  
REVERSE OSMOSIS  
PROCESS PERFORMANCE SUMMARY

Parameter	Geometric Mean mg/L		Percent Removal	95 Percent Confidence Interval mg/L	
	Influent	Effluent		Lower	Upper
Anions (mg/L)					
Alkalinity	34.9	11.0	68.5	52.5	79.1
Chloride	49.6	<0.1	>99.8	—	—
Sulfate	137.5	<0.6	>99.6	—	—
Cations (mg/L)					
Calcium	71.9	1.1	98.5	97.8	99.0
Manganese	6.0	0.12	98.1	96.1	99.0
Potassium	5.0	0.5	88.9	80.6	93.6
Sodium	30.9	2.1	93.3	79.2	97.9
Nutrients (mg/L)					
NO <sub>3</sub> +NO <sub>2</sub> -N	5.64	0.13	97.7	84.1	99.7
NH <sub>3</sub> -N	0.04	0.72	—	—	—
TKN	0.83	0.41	50.4	-4.2	76.4
PO <sub>4</sub> -P	0.10	<0.01	>90	—	—

## Investigations of Alternative Process Designs

TABLE 10.3-12

RO PERFORMANCE DATA  
TRACE METALS  
N= 7 SAMPLES

Trace Metals (mg/L)	Feed Geometric Mean	Product Geometric Mean	Percent Removal	95% Confidence Interval	
				Lower	Upper
Aluminum MDL=0.003 mg/L	0.009	NC <sup>a</sup>	NC	--	--
Barium MDL=0.002 mg/L	0.015	NC	>86 <sup>b</sup>	—	—
Boron MDL=0.0040 mg/L	0.044	0.006	88.6	61.7	94.5
Chromium MDL=0.0002 mg/L	0.003	0.0004	83.97	24.1	96.6
Copper MDL=0.0012 mg/L	0.003	NC	>60	—	—
Iron MDL=0.003 mg/L	0.019	0.007	62.3	-41.0	90.0
Lithium MDL=0.0004 mg/L	0.005	0.0006	86.7	70.0	94.2
Manganese MDL=0.0010 mg/L	0.007	NC	>86	—	—
Nickel MDL=0.0010 mg/L	0.001	NC	NC	—	—
Selenium MDL=0.0002 mg/L	0.0004	0.0002	63.1	-75.6	92.3
Vanadium MDL=0.0020 mg/L	0.002	NC	NC	—	—
Zinc MDL=0.0012 mg/L	0.004	0.001	71.1	12.4	90.5

a. NC = Not Calculated, less than 15 percent of samples were quantified

b. Removal completed based on MDL.

# Investigations of Alternative Process Designs

TABLE 10.3-13  
TOC AND TOX SUMMARY

Trace Organics	Feed			Product			95% Confidence Interval	
	Number Sampled	Number Quantified	Geometric Mean	Number Sampled	Number Quantified	Geometric Mean	Lower	Upper
Total Organic Carbon (mg/L-C)	39	39	3.028	39	39	0.593	77.9	82.7
Total Organic Halide (µg/L-Cl <sup>-</sup> )	16	15	67.7	14	1	NC <sup>1</sup>	NC	NC
TTHMS (µg/L)	16	16	2.45	16	15	1.19	24.8	68.5
TCE (µg/L)	16	8	NC	16	0	NC	—	—
PCE (µg/L)	16	15	0.54	16	14	.32	7.5	61.2

NC = Not Calculated



## Investigations of Alternative Process Designs

averaged about fifty percent with upper and lower 95 percent confidence intervals of 17 to 75 percent.

### RECOMMENDATIONS

The short term test of the polyamide hollow fiber RO process demonstrated that this RO unit could effectively reduce the levels of most problem water quality parameters to levels acceptable for human consumption. Notably, sodium and nitrate levels were reduced below their corresponding recommended (sodium) or regulated (nitrate) MCLs.

The process also showed a marked effect on reduction of total organic halide, a surrogate parameter measuring the levels of some organic compounds of health significance. Levels of this parameter were reduced below detection limits in all samples.

No attempts were made to address several important design issues which will arise if the RO process should be required in a full-scale estuary water treatment plant. Some of these issues include:

- membrane life
- post treatment for adjustment of pH and corrosion potential
- optimum configuration of the permeator modules
- optimum operating pressure
- the effect of temperature on the removal of individual parameters
- brine disposal alternatives

Based on the results of the monitoring program, however, the RO process is a feasible unit process for control of sodium, nitrate, TDS, and higher molecular weight organic compounds and most other parameters of concern. The polyamide membranes did not appear capable of controlling ammonia, however.

Should it be necessary to use a demineralization process in the estuary water treatment for control of specific inorganic contaminants, the RO process using polyamide fiber membranes would be a costly but technically feasible solution. Preliminary estimates of cost are provided in Chapter 11.

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## **CHAPTER 11**

### **PROCESS ALTERNATIVES AND COSTS**

This chapter discusses the treatment processes and resultant costs for a full-scale water treatment plant using the Potomac estuary as the raw water source if the plant were based upon the treatment processes tested and monitored at the EEWTP. Capital and operating costs are estimated for a 200 MGD treatment plant for two of the three process combinations evaluated. The cost estimates are presented to serve as a basis for any comparisons between constructing and operating an estuary treatment plant and other alternatives proposed for meeting the long-term water supply needs of the Metropolitan Washington Area.

Also included in this chapter are discussions of several treatment processes and operating conditions that were either studied on a smaller scale or were studied for too brief a period of time to adequately demonstrate their ability to produce a desired water quality. Evaluations are presented to display the impact of these processes and operating conditions on water quality and cost.

## SECTION 1

### OVERVIEW

As discussed in Chapter 1, concerns for meeting the long-term water supply needs in the Metropolitan Washington Area (MWA) have led to the development of various alternatives, one of which is the construction and operation of a water treatment plant using the Potomac estuary as the raw water source. To aid in comparing this estuary water treatment plant with other alternatives, cost estimates have been made.

Cost estimates are provided for two of the three process configurations tested at the EEWTP. The two process configurations are: 1) alum coagulation, intermediate oxidation with chlorine, gravity filtration, granular activated carbon adsorption, and free chlorine disinfection; and 2) lime coagulation, gravity filtration, granular activated carbon adsorption, final disinfection with ozone, and chloramination for a residual disinfectant. The design criteria for the full-scale plant were based on EEWTP operating results and accepted engineering practice. The estimated costs are intended to represent full-scale costs for an estuary treatment plant designed and operated similarly to the EEWTP processes demonstrated, and thus produce a water of similar quality. For comparison, costs are also estimated for a "conventional" full-scale plant. "Conventional" in this context is defined as a treatment plant employing commonly used processes to treat a river water source.

In addition to the plant-scale monitoring programs at the EEWTP, several alternative processes for organics control were evaluated in smaller scale, as discussed in Chapter 10. These included: air stripping in packed towers for the control of volatile organic chemicals; the evaluation of alternative design parameters for granular activated carbon adsorption, including the use of different carbons and different empty-bed contact times; and reverse osmosis. Also, different design criteria for coagulation, filtration, and disinfection processes were evaluated during various short-term tests conducted at the EEWTP. These processes and conditions not monitored at plant-scale or not monitored for prolonged periods of time are discussed with emphasis on their impact on water quality and costs.

Finally, of importance to the successful operation of a full-scale estuary treatment plant would be the cost and water quality implications of several water quality factors that could not be monitored. The impact of these factors on water quality and treatment plant costs is presented.

## SECTION 2

### OVERVIEW OF FULL-SCALE PLANT

The estuary treatment plant was considered to be a separate facility using the estuary as a raw water source and with two alternatives for use of the finished water: 1) pumping the finished water upstream along the Potomac River and releasing into the river several miles above current water intakes; and, 2) pumping the finished water directly to points within the MWA utilizing existing distribution systems.

The details of this proposed estuary water treatment plant are still uncertain. Because of the current water supply situation in the MWA, which indicates that no serious shortages are likely to occur until well into the next century, the proposed estuary water treatment plant remains hypothetical in many respects. Based upon these uncertainties, it was necessary in estimating the cost of the full-scale plant to make reasonable assumptions pertaining to the water source, plant capacity, operational strategy, and facilities included in the cost estimates. The assumptions do not impact on the actual estimated costs of the treatment processes themselves.

### WATER SOURCE

For these cost estimates, it was assumed that the water intake for the estuary treatment plant would be near Chain Bridge, the point in the Potomac River estuary exhibiting the highest water quality in the estuary under drought conditions. The predicted water quality under drought conditions near Chain Bridge was also the basis for selection of the equal mix of Blue Plains nitrified effluent and river water used as the influent to the EEWTP.

### PLANT CAPACITY AND OPERATIONAL STRATEGY

The original proposal for an estuary water treatment plant discussed a proposed plant capacity of 100 to 200 MGD. For cost comparisons, only costs for a 200 MGD plant are presented.

It is assumed that the 200 MGD hypothetical plant will be operated at 100 percent capacity for 365 days a year. Costs were developed primarily based on conservative estimates of the costs of such a proposed estuary water treatment plant. The cost estimates also do not account for the possibility that either the entire water treatment plant or portions of the water treatment plant would not be operated every day of the year, as opposed to operating only under drought conditions. It was assumed that the plant was operated to produce a finished water that would be distributed directly to consumers via existing distribution systems. If an estuary water treatment plant were actually built and operated, the water from the estuary plant could be blended

## Overview of Full-Scale Plant

with the existing finished waters from these water treatment plants or could serve as the raw water supply for other water treatment plants. Either situation could improve the quality of the water from the estuary water treatment plant before it reached consumers.

### FACILITIES INCLUDED IN COST ESTIMATES

Cost estimates are provided for each of the major process configurations demonstrated. Due to the unknown location of the full-scale plant and the unknown operating philosophy, the following facilities were excluded from cost estimates:

1. Intake Structure.
2. Intake Pumping Station.
3. Finished Water Pumping Station.
4. Finished Water Reservoirs.
5. Finished Water Distribution Piping.
6. Land Purchase.
7. Site Preparation (other than basic clearing and grading).
8. Fluoridation

The costs for these facilities would substantially increase the cost of a complete estuary water treatment plant. However, the estimated costs presented reflect the treatment costs necessary to produce a finished water of a quality similar to that produced by the EEWTP using a raw water source similar to that anticipated from the estuary during drought conditions. Cost estimates are based on the construction cost for "average site" conditions.

### SECTION 3

#### **FULL-SCALE PLANT PROCESS COMBINATION: ALUM/GAC/CHLORINE**

The first of two process combinations evaluated at the EEWTP selected for cost estimation is described as Phase IA in Chapter 7. A discussion of the operation of this process combination and the resulting water quality was included in Chapter 7. An evaluation of the finished water quality produced during Phase IA was discussed in Chapter 9. This section describes the processes and the design criteria that were used as the basis for the cost estimates.

#### **PROCESS DESCRIPTION**

The process combination that was studied during Phase IA includes the following treatment processes:

1. Coagulation with Alum and Polymers
2. Sedimentation
3. Intermediate Chlorination
4. Gravity Filtration
5. Adsorption on Granular Activated Carbon (15 minute Empty Bed Contact Time (EBCT))
6. Free Chlorine Disinfection
7. Solids Handling and Disposal

Although surface aeration and microscreening were also studied during Phase IA, they were not included in the design of the full-scale plant because operating results, as discussed in Appendix I, did not indicate sufficient benefit to warrant inclusion.

The purposes of the individual unit processes and EEWTP operating results are described in Chapter 7. A full-scale plant would include two additional chemical feed systems: permanganate as a chemical oxidant (to aid in iron and manganese removal); and lime for pH and corrosion control. Based upon limited bench-scale testing and on review of accepted practice in sludge handling and disposal, processes were included in the full-scale plant design for sludge thickening and dewatering with final sludge disposal by landfilling.

This process combination is not unique to the water treatment industry. Alum/polymer coagulation is widely used for chemical clarification. Permanganate is often used to oxidize a variety of substances in water, including manganese which was of concern in the operation of the EEWTP. Chlorination is the most commonly used disinfection process in the U.S. The intent of this process combination is to provide a free chlorine residual in the finished water from a water treatment plant. Even when ammonia is present in the raw water, breakpoint chlorination can yield the desired free chlorine residual. Although

**Full-Scale Plant Process Combination:  
Alum/GAC/Chlorine**

granular activated carbon is not widely used in water treatment in the U.S., it has been successfully used in European water treatment plants treating contaminated river sources. This GAC process uses a lignite based carbon and has an EBCT of fifteen minutes. Gravity thickening and centrifugation are proven and accepted means of sludge handling. In summary, this process combination employs proven water treatment processes.

**PROCESS AND MECHANICAL RELIABILITY**

A water treatment plant must continuously supply safe water to the consumer. It is crucial that the treatment processes function as intended and be able to maintain satisfactory finished water quality under varying influent water quality conditions. It is imperative that the processes function mechanically as intended. The treatment plant must be properly designed, operated and maintained. This is even more important when the raw water source is either contaminated or subject to contamination.

Most water treatment plants include a variety of design factors that address the issues of process and mechanical reliability. Some of these are as follows:

1. Duplicate sources of electric power.
2. Stand-by power for essential plant elements.
3. Multiple units and equipment.
4. Holding tanks or basins to provide for emergency storage.
5. Flexibility of piping and pumping facilities.
6. Automatic alarms.

The intent of these design factors is to provide for certain safeguards that give a reasonable amount of mechanical reliability. It is unlikely however that any water treatment plant is fail-safe. However, if the impact of each unit process on the quality and quantity of water production is determined, the desired degree of reliability of each unit process can be established. The actual mechanical reliability of the critical components of each unit process can be compared with the desired reliability and an assessment of the need for component redundancy and alternative operational requirements can be made.

Although each unit process is critical to the efficient operation of the treatment facility, certain processes become particularly critical to meeting finished water quality goals.

For the Phase IA process combination, the rapid mix process functions to efficiently disperse coagulation chemicals into the plant flow stream and, in so doing, reduces the amount of chemicals required for effective treatment. While coagulation is vital to the removal of turbidity and some trace metal contaminants, the loss of the rapid mix process merely causes the inefficient use of chemicals and does not necessarily result in the failure to meet water quality goals. The loss of the flocculation process will produce similar inefficiencies without resulting in unacceptable finished water quality. Moreover, the total loss of the flocculation process is extremely unlikely because of its multiple identical component configuration. The total failure of the



## **Full-Scale Plant Process Combination: Alum/GAC/Chlorine**

sedimentation process is also unlikely because sedimentation requires few mechanical components except for sludge removal. The accumulation of sludges in this process cannot continue indefinitely without resulting in process failure. It is not critical in the short term, but is quite necessary on a regular, yet interruptible, basis.

The filtration process functions to remove colloidal and suspended solids and is critical to meeting finished water quality goals; therefore, this process cannot be allowed to fail. The GAC process is also critical to provide a barrier to undesirable organic chemicals present in the influent water. In an indirect manner, the GAC regeneration process is also vital in meeting treatment objectives because the loss of this process for any length of time could cause poor performance of the GAC process for removal of organic chemicals.

The chemical feed processes have a variety of functions, some of which must be fail-safe. Proper coagulation with alum is vital, as is lime addition for pH control and alkalinity addition. The polymer feed processes are sometimes essential for removal of some colloidal solids, but are usually only essential for reducing the use of other coagulant chemicals or increasing the efficiency of the process for solids removal. The essential disinfection role of chlorine makes its continuous application the single most critical link in the treatment train, especially when treating a contaminated source, and its application must not be interrupted.

The solids handling process is unique in that it does not directly affect the main plant flow stream. A long term failure of this process will result in the eventual failure of the sedimentation process through excessive sludge accumulation, but short term loss of the solids handling processes could be tolerated, provided that backwash solids from the gravity filters could be disposed of conveniently. If this were not the case, solids handling could become a critical process whose failure might lead to unacceptable disruptions of the plant flow.

From the discussions presented above, it is apparent that the alum and lime feed for coagulation, filtration, GAC adsorption and regeneration, and chlorine disinfection processes must not be interrupted in order to maintain acceptable finished water quality on a continuous basis.

Before an estuary water treatment plant was designed, a more detailed redundancy analysis would be required to assure near fail-safe operation. One technique used to quantify the needed equipment and instrumentation redundancy is fault tree analysis.

The estimated mechanical reliabilities of each of the major components for all of the proposed unit processes are presented in Table 11.3-1, based on JMM operating experience at numerous water treatment plants. Redundancy requirements for each process are shown in the Table.

This procedure allows for a more systematic evaluation of redundancy requirements. Fault tree analysis is an orderly description of the various occurrences within a system that can result in some undesired event. In the case of a water

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**TABLE 11.3-1  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A**

Process: Rapid Mix Function: Disperse Coagulants into Process Stream			
EQUIPMENT ITEMS	RELIABILITY	IMPACT OF FAILURE	MITIGATION/DESIGN IMPACT
High speed mixer (or pump in case of hydraulic flash mixer).	Very Good - estimated annual downtime of less than 1 wk.	Poor mixing can reduce effectiveness of coagulants; therefore, more coagulant is needed to produce same results.	Provide redundant unit; normal design is to have one unit.
Process: Flocculation Function: Agglomeration of Small Coagulated Particulates into Settleable and/or Filterable Particulates			
EQUIPMENT ITEMS	RELIABILITY	IMPACT OF FAILURE	MITIGATION/DESIGN IMPACT
Two-speed, vertical shaft, propeller or turbine-type flocculators.	Very Good - annual downtime of less than 1 wk estimated.	Slight for loss of a single unit. For concurrent loss of more than half of the units in one basin, (very unlikely) either higher chemical dosages or basin shutdown would be required.	Provide multiple units per basin and multiple basins so that single unit and single basin shutdowns do not significantly overburden remaining units or basins.

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**TABLE 11.3-1 (Continued)  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A**

Process: Solids Handling Function: Dewatering of Sludges to Facilitate Trucking to Landfill Disposal			
<b>EQUIPMENT ITEMS</b>	<b>RELIABILITY</b>	<b>IMPACT OF FAILURE</b>	<b>MITIGATION/DESIGN IMPACT</b>
Unthickened sludge pumps.	Fair - estimated annual downtime of 2 wks.	Solids removal from sedimentation process is impossible.	Short term solids storage in hoppers of sedimentation basins should be provided. Also, standby pumping unit is necessary.
Gravity thickeners.	Good - estimated annual downtime of 1 wk.	Solids cannot be thickened prior to dewatering; dewatering process may fail.	Two units should be provided with a minimum total capacity of the maximum anticipated sludge production rate.
Thickened sludge pumps.	Fair - estimated annual downtime of 2 wks.	Solids removal from thickeners is impossible.	Short terms solids storage in thickeners is possible. However, standby pumping unit should be provided.
Centrifuges.	Fair - estimated annual downtime of 4 wks.	Non-dewatered sludge cannot be trucked to landfill; could lead to process failure if not resolved.	Short term solids storage in thickeners is possible. However, at least one standby unit should be provided.
Centrifuge Polymer System.	Good - estimated annual downtime of 1 wk.	Inefficient dewatering in the centrifuges. To produce a truckable sludge, lower loadings on the centrifuges will be required.	Provide standby polymer feed pump. Also provide extra centrifuge capacity to accommodate no polymer episodes.

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**TABLE 11.3-1 (Continued)  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A**

<b>Process: Chemical Feed - Permanganate Function: Control of Taste and Odor Agents/Oxidation of Manganese (Mn)</b>			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
Dry feeder.	Good - estimated annual downtime of 1 wk.	Slight, if a prepared solution is available in mixing and/or use tanks. Will cause excessive manganese levels in finished water.	Because of concern for aesthetic impact of high Mn in finished water, standby feeder should be required. Short term storage should also be provided.
Mixing tank.	Good - estimated annual downtime of 1 wk.	No batches of solution can be prepared without mixer. Supply limited to solution in storage tanks.	Short term storage should mitigate loss of mixer. Provision of a portable standby mixer is recommended.
Metering pump.	Good - estimated annual downtime of 1 wk.	Loss of pump means loss of all feeding capabilities.	Provision of standby pump is highly recommended.
<b>Process: Chemical Feed - Lime Function: pH/Alkalinity Control</b>			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
Packaged storage/slaker slurry-ing system.	Fair - estimated annual downtime of 4 wks.	High potential for insufficient alkalinity and low pH values, resulting in high Mn values, corrosive finished water.	Since lime feed is essential at all times, a 100% backup system must be provided.
Feed pump.	Fair - estimated annual downtime of 4 wks.	Same as above.	Same as above.

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TABLE 11.3-1 (Continued)  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A

Process: Chemical Feed - Alum & Polymers Function: Chemical Coagulation/Particle Destabilization		EQUIPMENT ITEMS	RELIABILITY	IMPACT OF FAILURE	MITIGATION/DESIGN IMPACT
		Dry feeders/conc. chemical transfer pumps (polymers only).	Good - estimated annual downtime of 1 wk.	Slight, if prepared solution storage is available downstream. Total loss of polymer would necessitate high alum dosages.	Provision of short term solution storage should suffice.
		Mixing tanks (polymers only).	Good - estimated annual downtime of 1 wk.	No batches of solution can be prepared without mixer. Supply limited to solution in storage tanks.	Short term storage should mitigate loss of mixer. Provision of a portable standby mixer is advisable.
		Metering pumps.	Good - estimated annual downtime of 1 wk.	Loss of pump means loss of all feeding capabilities.	Provision of a standby pump is mandatory for alum and highly recommended for polymer.
Process: Chemical Feed - Chlorine Function: Control of Biological Growth/Disinfection					
		Storage tank.	Very good - estimated annual downtime of less than 1 wk.	No supply results in no disinfection capability, and loss of process	Provision for multiple storage units is mandatory. Automatic switch over between storage tanks (or cylinders) is advisable.
		Evaporators.	Fair - estimated annual downtime of 2 wks.	Inadequate rate of chlorine withdrawal from storage, so inadequate disinfection likely.	Provision of standby unit is mandatory.
		Chlorinators.	Good - estimated annual downtime of 1 wk.	Inadequate or no rate of chlorine application, resulting in inadequate disinfection, and possible loss of process.	Provision of standby unit is mandatory.

**Full-Scale Plant Process Combination:  
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**TABLE 11.3-1 (Continued)  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A**

Process: GAC Contact Function: Removal of Organic Material in Filter Effluent			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
Influent pumps.	Good - estimated annual downtime of 1 wk.	Loss of process. If no bypass is provided, plant flow rate must be drastically reduced or stopped.	Provide process bypass so that flow can proceed by gravity to disinfection/clearwell. Also, provide at least one standby pump.
Gravity GAC Contactors Influent/Effluent Control Systems	Good - estimated annual downtime of 1 wk.	Higher surface loading rates in remaining contactors; possible hydraulic failure.	Provide adequate number of parallel contactors to minimize flow surges on remaining operational units.
Process: GAC Regeneration Function: Restoration of Organic Adsorptive Capacity of GAC			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
Hydraulic eductor/decant tank/ inlet conveyors.	Good - estimated annual downtime of 1 wk.	Loss of process. Extended period without this process yields partial to total loss of effectiveness of the GAC Process for removal of organic compounds.	Provide piping flexibility so that each contactor can be served by either of two GAC eductor/conveyor units.
Multiple hearth furnaces.	Poor - estimated annual downtime of 10 wks.	Same as above.	Provide 25-50% standby capacity.

**Full-Scale Plant Process Combination:  
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**TABLE 11.3-1 (Continued)  
SUMMARY OF MECHANICAL RELIABILITY ANALYSIS  
FOR PROCESSES IN PHASE 1A**

<b>Process: Sedimentation</b> <b>Function: Removal of Flocculated Particulates and Other Suspended Solids by Gravity Settling, plus Collection and Concentration of Sludge</b>			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
<b>Clarifier Mechanism:</b>			
Chain and Flight w/cross collectors.	Fair - estimated annual downtime of 2 wks.	Higher sludge loading rates on remaining sedimentation basins and potential for septic conditions in sludge if sludge is not removed in reasonable amount of time (2 weeks to 2 months depending on organic content of sludge).	Since most downtimes can be controlled to scheduled maintenance periods, shutdowns can occur during non-critical treatment or low demand periods. However, a sufficient number of basins should be provided to mitigate impact of single basin shutdowns.
<b>Process: Filtration</b> <b>Function: Removal of Flocculated/Suspended Solids</b>			
<u>EQUIPMENT ITEMS</u>	<u>RELIABILITY</u>	<u>IMPACT OF FAILURE</u>	<u>MITIGATION/DESIGN IMPACT</u>
Filter (w/control valves, under-drains, piping, etc.)	Good - estimated annual downtime of 1 wk.	Filter must be removed from service; other filters must be loaded at higher rate.	Size filters to operate at design loading rate with a minimum of two filters removed from service.
Air scour system (w/ compressor, piping, etc.)	Good - estimated annual downtime of 1 wk.	Backwash energy will be insufficient to effectively remove entrained particles.	Either provide standby compressor capability or oversize the pumped backwash system to be capable of operating alone. In the latter case, the underdrain system design will need to accommodate both cases (air and no air).
Pumped backwash system (w/ pumps, piping, etc.)	Good - estimated annual downtime of 1 wk.	Backwash energy will be insufficient to effectively remove entrained particles.	A standby pump must be provided.

## Full-Scale Plant Process Combination: Alum/GAC/Chlorine

treatment plant, an undesired event would be the failure of one of the plant's treatment processes and sudden reduction in finished water quality.

Fault tree analysis can be applied to a sequence of processes or to the entire treatment plant. The analysis evaluates the events leading to some major system failure as the top event. The components of the system that could cause failure are noted and they in turn are analyzed to determine what could cause their failure. The procedure allows the analyst to determine what components should be monitored by instrumentation or what equipment or instrumentation redundancy may be needed to reduce the probability of failure to some desired level.

In the event that an estuary water treatment plant is actually constructed, fault tree analysis should be used to evaluate additional instrumentation and equipment redundancies.

### SELECTION OF DESIGN CRITERIA

To estimate costs for a 200 MGD estuary water treatment plant based upon the alum/GAC/chlorine process combination, design criteria were selected as discussed below. Full-scale treatment plant cost estimates are based on costs for a treatment plant designed and operated similarly to this process combination as operated at the EEWTP. It is assumed that the finished water quality from the full-scale estuary water treatment plant would be similar to that produced by the EEWTP. In several instances, however, the EEWTP operating criteria were modified by engineering judgment if it was believed that the costs of the full-scale plant would be more realistic and that no difference in expected finished water quality would result.

### DESIGN CRITERIA FOR FULL-SCALE PLANT

The design criteria for a 200 MGD estuary water treatment plant, employing the alum/GAC/chlorine process combination tested during Phase IA of the EEWTP, are shown in Table 11.3-2. Shown are both a design capacity and an operating level. As mentioned previously, the operating and maintenance costs were estimated assuming the plant always operates at the 200 MGD capacity. The use of a 100 percent load factor is not a common engineering practice. For purposes of this project, however, such an assumption provides a more conservative cost estimate.

#### Chemical Feed Systems

Chemical dosages for alum, polymer, permanganate, and lime were selected based upon average dosages used during Phase IA when the processes were operating effectively as discussed in Chapter 7. Permanganate would be injected at the discharge of the raw water intake pumps. Alum and polymer would be added at the rapid mix tank and lime would be added after sedimentation and prior to gravity filtration.



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TABLE 11.3-2  
DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
ALUM/GAC/CHLORINE PROCESS

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
1. ALUM FEED			
Dose	mg/L	80.0	50.0
2. POLYMER FEED (Coagulation)			
Dose	mg/L	1.0	0.1
3. PERMANGANATE FEED			
Dose	mg/L	2.0	1.0
4. LIME FEED			
Dose	mg/L	30.0	15.0
5. RAPID MIX			
Detention Time	min	2	2
6. FLOCCULATION (1st Stage)			
G	sec <sup>-1</sup>	80	80
Detention Time	min	8	8
FLOCCULATION (2nd Stage)			
G	sec <sup>-1</sup>	50	50
Detention Time	min	8	8
FLOCCULATION (3rd Stage)			
G	sec <sup>-1</sup>	20	20
Detention Time	min	8	8
7. SEDIMENTATION			
Surface Overflow Rate	m <sup>3</sup> /m <sup>2</sup> -d (gpd/ft <sup>2</sup> )	41 (1,000)	41 (1,000)
8. POLYMER FEED (Filter Aid)			
Dose	mg/L	0.1	0.02
9. GRAVITY FILTER (Dual Media)			
Loading Rate	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	2 (3)	2 (3)

**Full-Scale Plant Process Combination:  
Alum/GAC/Chlorine**

**TABLE 11.3-2 (Continued)**

**DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
ALUM/GAC/CHLORINE PROCESS**

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>AIR-WATER BACKWASH</b>			
Air Flow	L/m <sup>2</sup> -s (ft <sup>3</sup> /min/ft <sup>2</sup> )	25 (5)	15 (3)
Pumping Capacity	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	10 (15)	8 (12)
<b>10. FILTERED WATER CLEARWELL</b>			
Volume	m <sup>3</sup> (gal)	8,000 (2,100,000)	8,000 (2,100,000)
<b>11. GAC FEED PUMPING</b>			
Flow	m <sup>3</sup> /s (MGD)	8.8 (200)	8.8 (200)
TDH	m (ft)	12 (40)	11 (35)
<b>12. GRAVITY GAC CONTACTORS</b>			
EBCT	min	15	15
Surface Loading	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	3 (5)	3 (5)
Surface Area/ Contactor	m <sup>2</sup> (ft <sup>2</sup> )	84 (900)	84 (900)
<b>BACKWASH PUMPING</b>			
Pumping Capacity	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	10 (15)	8 (12)
<b>13. GAC REGENERATION</b>			
<b>(Multiple Hearth Furnace)</b>			
Hearth Loading Rate	kg/m <sup>2</sup> /day (lb/day/ft <sup>2</sup> )	220 (45)	220 (45)

Full-Scale Plant Process Combination:  
Alum/GAC/Chlorine

TABLE 11.3-2 (Continued)

DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
ALUM/GAC/CHLORINE PROCESS

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>CARBON USAGE</b>			
Usage Rate	g/m <sup>3</sup> (lb/MG)	30 (250)	30 (250)
<b>MAKE-UP GAC</b>	% of that regenerated	N/A	10
<b>14. CHLORINATION</b> (Intermediate & Final)			
Chlorine Dose	mg/L	30.0	4.5
<b>15. FINISHED WATER CLEARWELL/CHLORINE CONTACT</b>			
Detention Time	min	60	60
<b>16. WASHWATER STORAGE</b>			
Volume	m <sup>3</sup> (gal)	3,400 (900,000)	3,400 (900,000)
<b>17. WASHWATER PUMPING</b>			
Pumping Capacity	m <sup>3</sup> /s (MGD)	0.12 (2.7)	0.04 (0.9)
<b>18. SLUDGE PUMPING UNTHICKENED</b>			
Flow	L/s (gpm)	120 (2,000)	60 (1,000)
<b>19. GRAVITY THICKENER</b>			
Solids Loading	kg/m <sup>2</sup> -d (lbs/ft <sup>2</sup> /day)	19.5 (4.0)	19.5 (4.0)
<b>20. SLUDGE PUMPING THICKENED</b>			
Flow	L/s (gpm)	21 (334)	11 (167)
<b>21. CENTRIFUGATION</b>			
Sludge Loading	L/s (gpm)	21 (334)	11 (167)
<b>POLYMER FEED</b>			
Dose	mg/L	30.0	20.0

Full-Scale Plant Process Combination:  
Alum/GAC/Chlorine

TABLE 11.3-2 (Continued)

DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
ALUM/GAC/CHLORINE PROCESS

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>22. DEWATERED SLUDGE HAULING</b>			
Quantity hauled	m <sup>3</sup> /yr (yd <sup>3</sup> /yr)	55,200 (72,200)	55,200 (72,200)
Distance hauled, one-way	km (mi)	40 (25)	40 (25)

Rapid Mix

Rapid mix tanks have been designed based upon the two minute detention time used at the EEWTP and a mixing intensity with a G value of 900 sec<sup>-1</sup>. This is greater than the G value used at the EEWTP (approximately 400 sec<sup>-1</sup>), but the higher value is more typical of rapid mix design and will give more realistic operating costs.

Flocculation

Three stages of tapered flocculation are provided to ensure sufficient detention time and to allow for improved floc formation under varying water quality conditions. Only two stages were provided at the EEWTP.

Sedimentation

Rectangular clarifiers are designed based upon a surface overflow rate of 1,000 gpd/ft<sup>2</sup>. Although the EEWTP operated at approximately 500 gpd/ft<sup>2</sup>, because of the short-circuiting observed in tracer studies, this higher overflow rate is considered more representative of operating conditions and would generate more realistic cost estimates. Proper design of full-scale plant sedimentation tanks could allow a higher surface overflow rate without adversely affecting water quality, should one unit fail, for example.

Gravity Filtration

Design of the gravity dual-media filters is based upon a 3 gpm/ft<sup>2</sup> filtration rate as operated at the EEWTP. Although the EEWTP used only water backwashing, in an effort to minimize costs associated with backwashing, pumping and washwater storage, an air scour/water backwash system has been included in the design criteria.

## Full-Scale Plant Process Combination: Alum/GAC/Chlorine

### Filtered Water Clearwell

The filtered water clearwell was sized for fifteen minutes detention time at 200 MGD.

### Granular Activated Carbon Adsorption

GAC contactors are designed based on an empty bed contact time (EBCT) of fifteen minutes, the EBCT used at the EEWTP during Phase IA. A lignite based GAC was used during this phase of EEWTP and the design of the full-scale plant is based upon using this GAC type. After reviewing several potential full-scale GAC designs, it was decided, based upon cost considerations and flexibility of operation, to use 64 concrete gravity contactors, with 32 sets of two-stage contactors. Thirty-one sets would be in operation at any one time with one set on standby. Each contactor would have a surface area of 900 ft<sup>2</sup> and have a hydraulic loading rate of 5 gpm/ft<sup>2</sup>. The carbon depth in each contactor would be 5 ft.

### GAC Regeneration

Regeneration frequencies are based upon those observed during Phase IA. As discussed in Chapter 7, the ICI 816 GAC was regenerated twice. The carbon usage rate based upon the amount of carbon used to treat the volume of water processed in Phase IA was 250 lbs/MG. This was the actual usage rate that produced the finished water quality discussed in Chapter 9. As shown in Chapter 7, the GAC was regenerated when the effluent TOC from the carbon contactors after 15 minutes EBCT consistently exceeded 2.0 mg/L. This same regeneration philosophy applies to the full-scale plant. This GAC design usage rate for the full-scale plant is conservative because full-scale parallel contactor operation could reduce the carbon usage by more than half. The cost implications of using parallel contactors and blending the treated water to some desired treatment objective are developed in Chapter 10 and discussed in Section 7 of this chapter. The parallel contactor carbon usage rate was not used for estimating costs for the full-scale plant because the water quality resulting from parallel contactor operation (blending) would not be the same as monitored during Phase IA.

Thermal regeneration is the most widely used method to reactivate the adsorption capacity of the GAC. On-site regeneration is generally perceived as being cost effective at any carbon usage rate greater than about 2,000 lb/day. Four types of thermal regeneration furnaces are currently used:

1. Multiple-hearth
2. Fluidized-bed
3. Rotary kiln
4. Infra-red electrical furnaces

A multiple-hearth furnace (MHF) was chosen for the full-scale plant because it is widely used. All four types of furnaces have various advantages and disadvantages with respect to quality of regenerated carbon and capital and

## Full-Scale Plant Process Combination: Alum/GAC/Chlorine

operating costs. As more full-scale operating experience is gained from these type of furnaces, it may be possible to use something other than a MHF and thereby reduce the cost of GAC treatment. In particular, the fluidized bed furnace shows promise for significantly reducing costs and should be evaluated for any full-scale estuary treatment plant.

For this cost estimate, a MHF is designed based upon a hearth loading rate of 45 lb/day/ft<sup>2</sup>. Two furnaces are used, one for standby, and it is assumed that each furnace will operate sixty percent of the time. This provides a conservative estimate for downtime due to mechanical problems and ensures that an operating furnace is available. It is assumed that the make-up GAC requirements will be ten percent of that regenerated.

### Chlorination

As operated at the EEWTP, chlorine is added at two places in the process flow:

1. Intermediate chlorination injected in-line prior to gravity filtration.
2. Final chlorination following GAC adsorption with sixty minutes of contact time provided in the final clearwell/chlorine contact tank.

Under normal operation, the intermediate chlorine dose will be 1.5 mg/L and the final chlorine dose will be 3.0 mg/L. Sufficient chlorination capacity is included to allow breakpoint chlorination at an influent ammonia concentration of 3.0 mg/L-N.

### Wastewater Storage and Pumping

Storage of filter and GAC contactor backwash water prior to recycling to the head of the plant is provided. Capacity is designed to store two backwashes of a filter and a GAC contactor.

### Solids Handling and Disposal

Selection and design of solids handling unit processes are based on EEWTP operation, limited bench-scale testing and analysis, and accepted water treatment plant practice. During Phase IA approximately 300 pounds of solids were produced per million gallons of treated water at an average solids concentration of 0.5 percent. Pumping units are provided for constant feed to gravity thickeners and solid-bowl centrifuges and sized with 100 percent redundancy to allow for equipment downtime or periods of higher solids production. Four gravity thickeners and two centrifuges are provided. It is assumed that the dewatered solids will be disposed of in a landfill.

### Administration, Laboratory and Maintenance Building

Costs for these buildings are based on a review of a number of water treatment plants. Costs developed include all costs for administrative, laboratory, and maintenance space and utilities, together with administrative supplies and labor costs for administrative and operations personnel. Most process maintenance

**Full-Scale Plant Process Combination:  
Alum/GAC/Chlorine**

equipment is included with each process and maintenance labor is also included with process costs.

**DISCUSSION OF DESIGN CRITERIA**

The design criteria described are based on EEWTP operating results and conservative engineering design. Equipment redundancy is provided consistent with water treatment plant practice and consistent with considerations presented in Table 11.3-1. The need for additional equipment redundancy and process monitoring instrumentation because of treating a water from a contaminated source is discussed in Section 7.

As mentioned, design criteria were for the most part conservative. It could be possible to decrease both capital and operating costs with certain modifications. Although not demonstrated at the EEWTP, such modifications should be feasible with negligible impact on water quality and are deserving of further consideration prior to an actual design. One example of where savings could result is the filtration loading rate. Properly conditioned water and properly designed filters could allow the filtration rate to increase from 3 to 6 gpm/ft<sup>2</sup>. Another example of savings is in sizing GAC regeneration processes based upon the blending of GAC treated water from a number of contactors operated in parallel. This would allow the GAC in each contactor to be more efficiently used prior to regeneration. The resulting savings would decrease the cost of using GAC. This and other GAC operating alternatives are discussed in Section 7.

## **SECTION 4**

### **FULL-SCALE PLANT PROCESS COMBINATION: LIME/GAC/OZONE/CHLORAMINE**

The second of two process combinations evaluated at the EEWTP for a full-scale 200 MGD cost estimation is the process combination described as Phase IIA in Chapter 8. A discussion of the operation of this process combination and the resulting water quality was included in Chapter 8. An evaluation of the finished water quality was discussed in Chapter 9. This section describes the processes and their design criteria that were used to estimate costs for a 200 MGD water treatment plant.

#### **PROCESS DESCRIPTION**

The process combination studied during Phase IIA that is the basis for a full-scale plant cost estimate includes the following processes:

1. Coagulation with Lime and Ferric Salts
2. Sedimentation
3. Recarbonation
4. Gravity Filtration
5. Adsorption on Granular Activated Carbon (30 minute EBCT)
6. Ozonation
7. Chloramination
8. Solids Handling and Disposal

As discussed in Chapter 8, this process combination was chosen for evaluation at the EEWTP to improve finished water quality and process reliability.

Although lime coagulation is not often used in water treatment except when softening is required, it was chosen to investigate possible improvements in TOC removal, to provide for better trace metals removal, and to provide for some disinfection prior to filtration that would not require chlorination. In addition, lime treated water was expected to be less corrosive. Several wastewater reclamation plants use lime as a primary coagulant. Ferric salts are often used with lime in water and wastewater treatment as a coagulant aid.

Two disadvantages of lime coagulation are the need for lowering the pH after coagulation to produce a stable water and the handling of the large amounts of solids produced. With a 200 MGD plant, it becomes practical to recalcine the lime sludge produced to recover the lime and to produce carbon dioxide for use in recarbonation. Recalcination also reduces the problems with final disposal of residual solids produced in the process. For these reasons, a recalcination furnace is proposed as part of the design of the full-scale plant.



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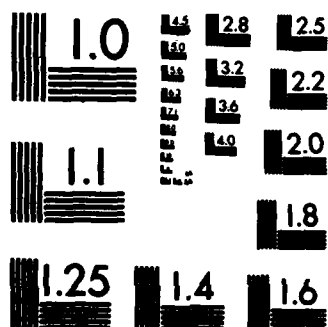
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## **Full-Scale Plant Process Combination: Lime/GAC/Ozone/Chloramine**

The GAC adsorption process in Phase IIA is different in two ways from that included in the Phase IA process combination. Based upon Phase IIA, the full-scale plant would use a bituminous based carbon and a longer EBCT of thirty minutes. It was believed that these changes would result in a longer lifetime of the carbon (less frequent regeneration) with resulting cost savings and would provide a better barrier for preventing the passage of synthetic organic chemicals into the finished water.

The other major difference between this process combination and the alum/GAC/chlorine process (Phase IA) was disinfection. The primary disinfectant in Phase IIA was ozone with chloramination providing a residual disinfectant. It was postulated that ozonation would provide equivalent or improved disinfection compared to free chlorine and that the use of ozone and chloramines would eliminate some of the chlorinous odors reported in Phase IA. In addition, chlorinated by-products would be minimized.

### **SELECTION OF DESIGN CRITERIA FOR FULL-SCALE PLANT**

Design criteria used for cost estimates were based upon operating results during Phase IIA and accepted water treatment plant practice. As with the cost estimate for the alum/GAC/chlorine process, the design criteria are generally conservative. The design criteria for a 200 MGD estuary water treatment plant employing the lime/GAC/ozone/chloramine process combination tested during Phase IIA of the EEWTP are shown in Table 11.4-1.

### **CHEMICAL FEED SYSTEMS**

Chemical dosages for lime and ferric sulfate were selected based upon average dosages used during Phase IIA. The operating lime dose was sufficient during periods of average alkalinity in the water to raise the pH to approximately 10.8. Sufficient design capacity is provided to raise the pH to approximately 11.5. Ferric sulfate is used as the ferric salt rather than the ferric chloride used in the operation of the EEWTP. Ferric sulfate has some chemical handling advantages and has been more widely used. Because of the high pH, ferrous sulfate could also be used effectively as a coagulant aid. As discussed in Chapter 8, ferric salts are used as a coagulant aid and sufficient design capacity is provided to allow for situations when more coagulant aid would be needed in chemical clarification.

### **RAPID MIX, FLOCCULATION, AND SEDIMENTATION**

The design criteria for these processes are the same as the alum/GAC/chlorine process. The design for the sedimentation tank is conservative using lime coagulation but is intended to describe closely the operation of the EEWTP.

**Full-Scale Plant Process Combination:  
Lime/GAC/Ozone/Chloramine**

**TABLE 11.4-1**

**DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
LIME/GAC/OZONE/CHLORAMINE PROCESS**

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
1. LIME FEED			
CaO Dose	mg/L	200.0	75.0
2. FERRIC SULFATE FEED			
Dose	mg/L	11.0	3.0
3. RAPID MIX			
Detention Time	min	2	2
4. FLOCCULATION (1st stage)			
G	sec <sup>-1</sup>	80	80
Detention Time	min	8	8
FLOCCULATION (2nd stage)			
G	sec <sup>-1</sup>	50	50
Detention Time	min	8	8
FLOCCULATION (3rd stage)			
G	sec <sup>-1</sup>	20	20
Detention Time	min	8	8
5. SEDIMENTATION			
Surface Overflow			
Rate	m <sup>3</sup> /m <sup>2</sup> -d (gpd/ft <sup>2</sup> )	41 (1,000)	41 (1,000)
6. RECARBONATION BASIN			
Detention Time	min	20	20
CARBON DIOXIDE SUPPLY			
Capacity	kg CO <sub>2</sub> /d (lbs CO <sub>2</sub> /day)	118,000 (260,000)	59,000 (130,000)
7. POLYMER FEED			
(Filter Aid)			
Dose	mg/L	0.1	0.01
8. GRAVITY FILTER			
(Dual Media)			
Loading Rate	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	2 (3)	2 (3)

**Full-Scale Plant Process Combination:  
Lime/GAC/Ozone/Chloramine**

**TABLE 11.4-1 (Continued)**

**DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
LIME/GAC/OZONE/CHLORAMINE PROCESS**

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>AIR-WATER BACKWASH</b>			
Air Flow	L/m <sup>2</sup> -s (ft <sup>3</sup> /min/ft <sup>2</sup> )	25 (5)	15 (3)
Pumping Capacity	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	10 (15)	8 (12)
<b>9. FILTERED WATER CLEARWELL</b>			
Volume	m <sup>3</sup> (gal)	8,000 (2,100,000)	8,000 (2,100,000)
<b>10. GAC FEED PUMPING</b>			
Flow	m <sup>3</sup> /s (MGD)	8.8 (200)	8.8 (200)
TDH	m (ft)	12 (40)	11 (35)
<b>11. GRAVITY GAC CONTACTORS</b>			
EBCT	min	30	30
Surface Loading	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	3 (5)	3 (5)
Surface Area/ Contactor	m <sup>2</sup> (ft <sup>2</sup> )	84 (900)	84 (900)
<b>BACKWASH PUMPING</b>			
Pumping Capacity	L/m <sup>2</sup> -s (gpm/ft <sup>2</sup> )	10 (15)	8 (12)
<b>12. GAC REGENERATION</b>			
(Multiple Hearth Furnace)			
Hearth Loading Rate	kg/m <sup>2</sup> -d (lb/day/ft <sup>2</sup> )	220 (45)	220 (45)

**Full-Scale Plant Process Combination:  
Lime/GAC/Ozone/Chloramine**

**TABLE 11.4-1 (Continued)**

**DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
LIME/GAC/OZONE/CHLORAMINE PROCESS**

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>CARBON USAGE</b>			
Usage Rate	g/m <sup>3</sup> (lb/MG)	42 (350)	42 (350)
<b>MAKE-UP GAC</b>	% of that regenerated	N/A	10
<b>13. OZONE GENERATION</b>			
Dose	mg/L	6.0	2.0
<b>OZONE CONTACT TANK</b>			
Detention Time	min	20	20
<b>14. AMMONIA FEED</b>			
Dose	mg/L	2.0	1.0
<b>15. CHLORINE FEED</b>			
Dose	mg/L	6.0	3.0
<b>16. FINISHED WATER CLEARWELL</b>			
Detention Time	min	60	60
<b>17. WASHWATER STORAGE</b>			
Volume	m <sup>3</sup> (gal)	3,400 (900,000)	3,400 (900,000)
<b>18. WASHWATER PUMPING</b>			
Pumping Capacity	m <sup>3</sup> /s (MGD)	0.12 (2.7)	0.04 (0.9)
<b>19. SLUDGE PUMPING UNTHICKENED</b>			
Flow	L/s (gpm)	90 (1,440)	45 (720)
<b>20. GRAVITY THICKENER</b>			
Solids Loading	kg/m <sup>2</sup> -d (lbs/ft <sup>2</sup> /day)	195 (40)	195 (40)
<b>21. SLUDGE PUMPING THICKENED</b>			
Flow	L/s (gpm)	23 (360)	12 (180)

**Full-Scale Plant Process Combination:  
Lime/GAC/Ozone/Chloramine**

TABLE 11.4-1 (Continued)

**DESIGN CRITERIA  
200 MGD ESTUARY WATER TREATMENT PLANT  
LIME/GAC/OZONE/CHLORAMINE PROCESS**

<u>Process</u>	<u>Units</u>	<u>Design Capacity</u>	<u>Operating Level</u>
<b>22. CENTRIFUGATION</b>			
Sludge Loading	L/s (gpm)	23 360)	12 (180)
<b>POLYMER FEED</b>			
Dose	mg/L	30.0	20.0
<b>23. RECALCINATION (MULTIPLE HEARTH)</b>			
Hearth Loading Rate (Wet Sludge Basis)	kg/m <sup>2</sup> -h (lb/hr/ft <sup>2</sup> )	40 (3)	40 (8)

**RECARBONATION**

Carbon dioxide from the stack gas of the recalcination furnace is to be compressed and returned to a recarbonation basin. Two recalcination furnaces are provided with an assumed downtime of thirty percent each. This ensures that one furnace will operate continuously. One furnace in operation can supply the CO<sub>2</sub> necessary for recarbonation. Twenty minutes of contact time is provided in the recarbonation basin. The operating level of CO<sub>2</sub> capacity is designed to lower the pH of the average lime treated water to a pH between 7.5 and 8.0. The design capacity is sufficient to lower the pH from 11.5 to the same level.

**GRAVITY FILTRATION AND FILTERED WATER CLEARWELL**

The design criteria are the same as for the alum/GAC/chlorine process combination.

**GRANULAR ACTIVATED CARBON ADSORPTION**

GAC contactors are designed based on an EBCT of thirty minutes, the same as used in Phase IIA. The bituminous based GAC used at the EEWTP is to be used in the full-scale plant. The design is based on using 64 concrete gravity contactors operating in the same two-stage operation as discussed for the alum/chlorine process combination. The carbon depth in the 900 ft<sup>2</sup> surface area contactors is 10 ft.

## **Full-Scale Plant Process Combination: Lime/GAC/Ozone/Chloramine**

### **GAC REGENERATION**

Regeneration frequencies are based upon the amount of carbon used in Phase IIA to treat the volume of water processed. To evaluate the benefit of the thirty minute EBCT, the flow through the EEWTP carbon contactors was reduced to 0.25 MGD. As shown and discussed in Chapter 8, the TOC level in the water from the GAC contactors was approaching approximately 1.5 mg/L-C when the EEWTP operation ended. The GAC used in Phase IIA was never regenerated. As a conservative design usage rate for the full-scale plant, and as a usage rate that describes the operation of the GAC process that produced the finished water quality discussed in Chapter 9, the amount of carbon actually used in Phase IIA to treat the water processed was used as the design carbon usage rate. This usage rate was 350 lb/MG. It should be emphasized the GAC process costs for this process combination are not comparable with those from the alum/GAC/chlorine process because the EBCTs were different and the carbon usage rates are based on different regeneration criteria.

As with the alum/GAC/chlorine process, full-scale parallel contactor operation could greatly reduce the carbon usage rate. This will be discussed in Section 7.

On-site regeneration using a multiple-hearth furnace is assumed. The design criteria for the MHF are the same as the alum/GAC/chlorine process combination.

### **OZONATION**

Ozone generation capacity was selected based upon operating results of the EEWTP. The design capacity is set at three times the operating level. An ozone contact tank is provided with a twenty minute detention time.

### **CHLORAMINATION**

Ammonia and chlorine feed systems are designed based upon EEWTP operating data. Sufficient capacity is provided to allow for flexible operation.

### **FINISHED WATER CLEARWELL, WASHWATER STORAGE AND PUMPING**

Design criteria are the same as the alum/GAC/chlorine process combination. Although the detention time in the finished water clearwell (chloramination contact tank) during Phase IIA was 120 minutes, a 60 minute contact time was used in sizing the clearwell (the same as used for Phase IA). This reduction will not affect finished water quality based on the results of the Phase IIA monitoring.

### **SOLIDS HANDLING AND DISPOSAL**

The solids handling and disposal processes are sized based upon the solids production during Phase IIA. Design is based upon a solids generation of 2,200 pounds per million gallons of water treated at an average solids concentration of five percent. Pumping units are provided for constant feed to gravity



## SECTION 5

### COST ESTIMATES OF PROCESS COMBINATIONS MONITORED

Based upon the design criteria specified in Sections 3 and 4, cost estimates have been prepared for a 200 MGD estuary water treatment plant. These cost estimates do not include all the facilities that would be required in constructing an estuary water treatment plant. As previously discussed, because of the hypothetical nature of the estuary plant, cost estimates are provided only for the water treatment processes. Those facilities not included in the cost estimates were listed in Section 2 of this chapter.

#### METHODS USED TO ESTIMATE COSTS

The methods used to generate cost estimates are a hybrid of two types of cost estimates: study and preliminary. Study estimates require flow diagrams, material and energy balances, and knowledge of types and sizes of equipment. They are intended for generalized evaluations, guidance for further investigation, or as a basis for process selection. Their usual accuracy is  $\pm 30$  percent. Preliminary estimates require more detail including some engineering of the structures and facilities. These estimates are often the basis for a decision to undertake detailed engineering or are sometimes the basis for budget authorizations. Their usual accuracy is  $\pm 20$  percent.

Both levels of estimates have been used in the cost estimates presented. Some processes were subjected to a preliminary cost estimate, for example, the GAC adsorption process. Because this process was central to both process combinations considered and because this process is not usually employed in water treatment due to its high cost, a more detailed cost estimate was warranted.

The cost estimates of the full-scale plant were first made using a FORTRAN computer program ("WATER") prepared for the EPA (Lineck, et al, 1979). The computer program determined costs by retrieving stored coefficients for a least squares polynomial fit of cost curves which had been generated for 72 unit processes used in water treatment. The cost curves were based on conceptual designs of water supply systems with capacities between 1 and 200 MGD. Process capital and O&M costs are plotted versus an appropriate design parameter, such as pounds per day for chemical feed systems or square feet of surface area for gravity filters. For a further description of the development of the individual cost curves, reference can be made to the original EPA documentation (Gumerman, et al, 1979).

The costs generated by the program include capital costs and operation and maintenance costs. Capital costs consist of the construction costs for each unit process, together with additional capital cost for sitework and interface piping, subsurface considerations, standby power, contractor overhead and profit, engineering, legal, fiscal and administration services, and interest during

## Cost Estimates of Process Combinations Monitored

construction. Operation and maintenance costs include those for electricity, labor, maintenance materials, diesel fuel, natural gas, and chemicals.

These costs were also compared with other water treatment plant cost information as a check on the reasonableness of the computer cost estimates. In some cases preliminary engineering was required to generate estimates.

All costs are updated to April, 1983 dollars. Various cost indices used to update original cost data are listed in Table 11.5-1. The indices reflect the current economic climate and construction costs in the Baltimore area and were believed to be a sound basis for the estuary water treatment plant costs. Eight different indices were used for different portions of construction and O&M costs. Use of the eight separate indices was compared with costs based on the Engineering News Record (ENR) Construction Cost Index (CCI) and was found to generate costs eleven to thirteen percent lower than using the CCI. This more closely matched JMM's data on water treatment plant costs and therefore was the basis for cost up-dating.

### ESTIMATED COSTS

Estimated costs for a 200 MGD estuary water treatment plant for the alum/GAC/chlorine and lime/GAC/ozone/chloramine process combinations are shown in Tables 11.5-2 and 11.5-3, respectively. Shown for the individual processes and grouping of processes are the capital costs, the annual operation and maintenance costs, and the unit cost in cents per 1,000 gallons. Costs based on metric units are also given. This unit cost was based on amortizing the capital costs over a twenty year period at eight percent interest. The cost criteria used in developing the cost estimation are shown in Table 11.5-1.

The total annual treatment costs for the alum/GAC/chlorine process were 25.03 million dollars and consisted of 12.46 million dollars in annual amortized capital costs and 12.57 million dollars in annual operation and maintenance costs. For the lime/GAC/ozone/chloramine process, the total annual treatment costs were 34.43 million dollars and consisted of 17.74 million dollars in annual amortized capital costs and 16.69 million dollars in annual operation and maintenance costs. Thus, in both cases operating costs contributed approximately fifty percent of the annual unit costs.

# Cost Estimates of Process Combinations Monitored

TABLE 11.5-1  
COST CRITERIA  
(April 1983)

## I. Capital Cost Factors (% of Construction Costs):

1. Engineering (%)	=	7.0
2. Sitework, interface piping (%)	=	5.5
3. Subsurface considerations (%)	=	1.0
4. Standby power (%)	=	1.0
5. Interest rate (%)	=	8.0
6. Number of years for capital cost amortization	=	20.0

## II. Unit Cost Factors:

1. Electricity (\$/KWH)	=	0.060
2. Labor (\$/hr)	=	12.000
3. Diesel fuel (\$/gal)	=	1.180
4. Natural gas (\$/ft <sup>3</sup> )	=	0.007 <sup>a</sup>
5. Building energy use (KWH/ft <sup>2</sup> /yr)	=	102.600

## III. Cost Indices (April, 1983, Baltimore):

1. Excavation (ENR skilled labor)	=	332.8
2. Manufactured equipment (BLS #114)	=	307.5
3. Concrete (BLS #132)	=	309.6
4. Steel (BLS #101.3)	=	340.3
5. Labor (ENR skilled labor)	=	332.8
6. Pipes & valves (BLS #114.901)	=	323.5
7. Electrical and instrumentation (BLS #117)	=	235.8
8. Housing (ENR Building Cost)	=	339.9
9. Producer Price Index	=	285.7
10. ENR Construction (1967 base year)	=	350.0 <sup>b</sup>

## IV. Chemical Costs:

1. Chlorine (\$/ton)	=	230
2. Alum (\$/ton)	=	147
3. Polymer (\$/ton)	=	6,000
4. Potassium permanganate (\$/ton)	=	2,056
5. Quicklime (\$/ton)	=	68
6. Ferric sulfate (\$/ton)	=	140
7. Anhydrous ammonia (\$/ton)	=	240

## V. Capital Recovery Factor (20 years, 8%) = 0.10185

- a. Based on use of Number 2 fuel oil @ \$1.00/gal to obtain equivalent BTU's.  
Assumes 1,000 BTU/ft<sup>3</sup> of natural gas versus 141,000 BTU/gal fuel oil.
- b. Not used in cost estimates but provided for reference.

# Cost Estimates of Process Combinations Monitored

TABLE 11.5-2

## ESTIMATED COSTS 200 MGD ESTUARY WATER TREATMENT PLANT ALUM/GAC/CHLORINE PROCESS (April 1983)

	Capital Costs (\$ Million)	Annual O & M Costs (\$ Million)	Cost in Cents/1,000 Gala (\$/1,000 m <sup>3</sup> )	
Alum Feed	0.46	2.25	3.19	(8.43)
Polymer Feed	0.08	0.19	0.28	(0.74)
Permanganate Feed	0.03	0.64	0.88	(2.32)
Lime Feed	0.23	0.35	0.53	(1.40)
Rapid Mix	1.13	0.85	1.42	(3.75)
Flocculation	2.04	0.84	1.62	(4.28)
Sedimentation	11.43	0.23	2.93	(7.74)
Subtotal	15.40	5.35	10.85	(28.66)
Polymer Feed	0.03	0.06	0.09	(0.24)
Gravity Filters & Media	12.54	0.85	4.03	(10.65)
Air/Water Backwash	3.02	0.14	0.88	(2.32)
Filtered Water Clearwell	0.58	0.00	0.13	(0.34)
Subtotal	16.17	1.05	5.13	(13.55)
GAC Feed Pumping	1.40	0.95	1.62	(4.28)
Contactors & Carbon	27.54	0.04	6.34	(16.75)
Backwash Pumping	0.50	0.07	0.21	(0.55)
Regeneration & Make-up Carbon	6.70	4.10	7.15	(18.90)
Subtotal	36.14	5.16	15.32	(40.48)
Chlorination (Intermediate and Final)	0.57	0.34	0.60	(1.59)
Finished Water Clearwell/Chlorine Contact	2.31	0.00	0.53	(1.40)
Washwater Storage	0.86	0.00	0.20	(0.53)
Washwater Pumping	0.06	0.01	0.03	(0.08)
Subtotal	0.92	0.01	0.23	(0.61)
Sludge Pumping	0.17	0.03	0.08	(0.21)
Gravity Thickening	0.78	0.02	0.21	(0.55)
Sludge Pumping	0.06	0.02	0.04	(0.11)
Polymer Feed	0.03	0.05	0.08	(0.21)
Centrifugation	1.34	0.07	0.40	(1.06)
Sludge Hauling	0.31	0.17	0.30	(0.79)
Subtotal	2.69	0.36	1.11	(2.93)

**Cost Estimates of Process Combinations Monitored**

**TABLE 11.5-2 (Continued)**

**ESTIMATED COSTS  
200 MGD ESTUARY WATER TREATMENT PLANT  
ALUM/GAC/CHLORINE PROCESS  
(April 1983)**

	<u>Capital Costs</u> <u>(\$ Million)</u>	<u>Annual</u> <u>O &amp; M Costs</u> <u>(\$ Million)</u>	<u>Cost in</u> <u>Cents/1,000 Gal<sup>a</sup></u> <u>(\$/1,000 m<sup>3</sup>)</u>
Admin, Lab & Maintenance Building	0.61	0.30	0.55 (1.4 <sup>f</sup> )
<b>TOTAL PROCESS</b>	<b>74.81</b>	<b>12.57</b>	<b>34.32 (90.6)</b>
Sitework @ 7.5%	5.61		
Contractor OH & Profit @ 15%	12.06		
<b>TOTAL CONSTRUCTION</b>	<b>92.48</b>		
Engineering @ 7%	6.47		
Legal, Fiscal, Admin	0.21		
Interest During Construction	12.02		
Contingency @ 10%	11.12		
<b>TOTAL CAPITAL</b>	<b>122.30</b>		

a. Includes costs for sitework, contractor overhead and profit, legal, fiscal and administrative, interest during construction, and contingency. These costs are not included in the capital costs shown for each process.

# Cost Estimates of Process Combinations Monitored

TABLE 11.5-3

## ESTIMATED COSTS 200 MGD ESTUARY WATER TREATMENT PLANT LIME/GAC/OZONE/CHLORAMINE PROCESS (April 1983)

	Capital Costs (\$ Million)	Annual O & M Costs (\$ Million)	Cost in Cents/1,000 Gal <sup>a</sup> (\$/1,000 m <sup>3</sup> )	
Lime Feed	0.24	0.22	0.37	(0.98)
Ferric Sulfate Feed	0.12	0.14	0.23	(0.61)
Rapid Mix	1.13	0.85	1.46	(3.86)
Flocculation	2.04	0.84	1.66	(4.39)
Sedimentation	11.43	0.23	3.00	(7.93)
Recarbonation	2.60	0.21	0.90	(2.38)
Subtotal	17.56	2.49	7.62	(20.15)
Polymer Feed	0.03	0.06	0.09	(0.24)
Gravity Filters & Media	12.54	0.85	4.13	(10.91)
Air/Water Backwash	3.02	0.14	0.91	(2.40)
Filtered Water Clearwell	0.58	0.00	0.14	(0.37)
Subtotal	16.17	1.05	5.29	(13.92)
GAC Feed Pumping	1.40	0.95	1.67	(4.41)
Contactors & Carbon	39.80	0.04	9.39	(24.81)
Backwash Pumping	0.53	0.08	0.24	(0.63)
Regeneration & Make-up Carbon	7.70	5.90	10.10	(26.69)
Subtotal	49.43	6.97	21.40	(56.54)
Ozone Generation	6.31	0.69	2.45	(6.47)
Ozone Contact	1.09	0.00	0.25	(0.66)
Subtotal	7.40	0.69	2.70	(7.13)
Ammonia Feed	0.13	0.09	0.16	(0.42)
Chlorination	0.33	0.24	0.42	(1.11)
Subtotal	0.46	0.33	0.58	(1.53)
Finished Water Clearwell	2.31	0.00	0.54	(1.43)
Washwater Storage	0.86	0.00	0.20	(0.53)
Washwater Pumping	0.06	0.01	0.03	(0.08)
Subtotal	0.92	0.01	0.23	(0.61)

**Cost Estimates of Process Combinations Monitored**

**TABLE 11.5-3 (Continued)**

**ESTIMATED COSTS  
200 MGD ESTUARY WATER TREATMENT PLANT  
LIME/GAC/OZONE/CHLORAMINE PROCESS  
(April 1983)**

	<b>Capital Costs</b> <b>(\$ Million)</b>	<b>Annual</b> <b>O &amp; M Costs</b> <b>(\$ Million)</b>	<b>Cost in</b> <b>Cents/1,000 Gala</b> <b>(\$/1,000 m<sup>3</sup>)</b>
Sludge Pumping	0.14	0.02	0.06 (0.29)
Gravity Thickening	0.43	0.01	0.11 (0.29)
Sludge Pumping	0.06	0.02	0.04 (0.11)
Polymer Feed	0.03	0.05	0.08 (0.21)
Centrifugation	1.39	0.07	0.42 (1.11)
Recalcination	10.00	4.00	7.97 (21.06)
Subtotal	12.05	4.12	8.68 (22.94)
Admin, Lab & Maintenance Building	0.61	0.30	0.57 (1.51)
<b>TOTAL PROCESS</b>	106.91	16.69	47.62 (125.76)
Sitework @ 7.5%	8.02		
Contractor OH & Profit @ 15%	17.24		
<b>TOTAL CONSTRUCTION</b>	132.17		
Engineering @ 7%	9.25		
Legal, Fiscal, Admin	0.26		
Interest During Construction	16.63		
Contingency @ 10%	15.83		
<b>TOTAL CAPITAL</b>	174.14		

a. Includes costs for sitework, contractor overhead and profit, legal, fiscal and administrative, interest during construction, and contingency. These costs are not included in the capital costs shown for each process.

## Cost Estimates of Process Combinations Monitored

It again should be emphasized that the cost estimates were generated based upon operating results from the EEWTP. As previously discussed, the carbon usage rate observed during operation of the lime/GAC/ozone/chloramine process combination is relatively high. This inflates the GAC costs and caution should be exercised if comparing costs with the alum/GAC/chlorine process combination. Possible reductions in GAC cost estimates will be presented and discussed in Section 7.

### COST COMPARISON WITH CONVENTIONAL WATER TREATMENT

The costs for the two process combinations monitored can be compared with a conventional water treatment plant treating a river water source. A realistic conventional water treatment plant would be the same as described in the alum/GAC/chlorine process combination without the GAC adsorption process. The cost comparison is shown in Table 11.5-4.

TABLE 11.5-4  
200 MGD  
COST COMPARISON OF CONVENTIONAL PROCESS  
WITH EEWTP PROCESSES MONITORED  
(April 1983)

<u>Treatment Configuration</u>	<u>Cost in Cents/ 1,000 Gal (\$/1,000 m<sup>3</sup>)</u>
Conventional Water Treatment Plant	19.00 (50.48)
Alum/GAC/Chlorine Process Combination	34.32 (90.67)
Lime/GAC/Ozone Process Combination	47.62 (125.76)

As shown, GAC causes a significant increase in unit costs. Thus, savings in GAC usage can result in reductions in unit costs. GAC provides an important barrier to SOCs and reduces the levels of precursors for formation of oxidation byproducts (e.g., THMs), but this added barrier is costly.



## **SECTION 6**

### **IMPLICATIONS OF VARIATIONS IN INFLUENT WATER QUALITY**

The cost estimates for a 200 MGD estuary water treatment plant presented in Section 5 were based upon process combinations monitored at the EEWTP. These costs are, therefore, related to the finished water qualities produced during the different phases of EEWTP operation discussed in Chapter 9. The finished water quality in a full-scale estuary water treatment plant will be dependent on the influent raw water quality of the estuary during drought conditions. It is possible that the full-scale plant may be subjected to different influent water qualities than that monitored during the two-year operation of the EEWTP. It is necessary then to consider the implications of some of these possible variations in influent water quality on the process reliability of the configurations recommended for the estuary plant.

#### **INFLUENT WATER QUALITY VARIATIONS**

To a large extent, the process combinations monitored are expected to adapt to reasonable changes in concentration of most of the water quality parameters. The process evaluations in Chapters 7 and 8 indicated that the monitored process combinations maintained acceptable removal efficiencies when the influent concentrations of selected water quality parameters varied. Variations in certain parameters could reduce process performance, however, and these issues must be addressed. Parameters in this category include temperature, total dissolved solids, nitrate, and unpredictable contamination of certain parameters contributed by spills, urban runoff and wastewater discharges.

#### **TEMPERATURE**

Time-series plots of temperature of the influent water at the EEWTP were shown in Chapters 7 and 8. Water temperature decreased from September until March. Because of the proximity of the EEWTP to the Blue Plains Wastewater Treatment Plant, the wastewater contribution to the blended influent maintained the water temperature higher than would be expected during winter months at an estuary water treatment plant. The blended influent reached a low temperature of approximately 6°C. An estuary water treatment plant located at Chain Bridge would encounter temperatures as low as 0°C.

During February of 1983, the nitrified wastewater influent supply line to the EEWTP was severed. For several weeks, the influent was entirely from the estuary which had a temperature of 2 to 4°C. There was a noticeable decrease in the floc formation after lime and ferric chloride addition. The removal efficiency of the chemical clarification process decreased slightly and the turbidities in the gravity filter effluent were higher than normal. An increase in ferric chloride dose, however, improved the chemical clarification process

## Implications of Variations in Influent Water Quality

performance. EEWTP operation ended in March precluding any experimentation with various polymers, but it is likely that one could have been found to allow the chemical clarification process to operate efficiently during periods of treating water under low temperature conditions. No other adverse responses were noticed during this period. Although temperature can affect the GAC adsorption process, the anticipated temperature levels are not expected to have any adverse impact on GAC adsorption.

A principal issue, however, is the fact that drought events traditionally occur in summer or fall seasons when the water temperature exceeds 20°C. Even if the full-scale estuary water treatment plant were to operate 365 days a year, sufficient chemical feed flexibility would be incorporated in the plant design to allow for efficient operations under the lower water temperatures. Therefore, the fact that the demonstration plant was operated over temperature ranges that did not simulate winter conditions is not likely to affect finished water quality adversely.

### TOTAL DISSOLVED SOLIDS (TDS)

The process combinations monitored at the EEWTP were not capable of removing TDS from the water. Based upon the estuary water quality modeling study conducted for this project, TDS levels were not expected to exceed the secondary MCL of 500 mg/L. However, the Metropolitan Washington Area Water Supply Study suggests that TDS levels at Chain Bridge may reach levels on the order of 1,000 mg/L, based on use of the Chesapeake Bay Hydraulic Model operated by the U.S. Army Corps of Engineers.

If TDS levels are consistently above the SMCL of 500 mg/L, removal in a full-scale estuary water treatment plant may be desirable. Additional modeling studies should be conducted prior to the design of an estuary water treatment plant to determine the need for TDS removal. If TDS removal is necessary, one recommended process that was evaluated at the EEWTP is reverse osmosis (RO). RO is capable of over ninety percent removal of TDS and also removes other dissolved inorganic and organic parameters of potential health concern, as discussed in Chapter 10.

### NITRATE

Monitoring at the EEWTP revealed higher nitrate levels in the water than originally projected for the estuary under drought conditions (see Chapters 6 and 9). The process combinations monitored do not remove nitrate. Although the EEWTP finished water sometimes exceeded the nitrate MCL of 10 mg/L, it only occurred when the EEWTP influent raw water was 100 percent Blue Plains nitrified effluent. However, as discussed in Chapter 6, projected maximum nitrate levels at Chain Bridge are estimated to be as high as 9 mg/L which is close to the primary MCL.

As with TDS, enhanced modeling efforts should be made prior to the design and construction of an estuary water treatment plant to verify whether or not nitrate would be a problem parameter. Should that be the case, nitrate removal would be required, and could be achieved by reverse osmosis.

### UNPREDICTABLE CONTAMINATION

The estuary is an unprotected water source subject to contamination from numerous point and non-point sources. Of particular concern would be synthetic organic chemicals of industrial origin. These could either pass through the estuary water treatment plant at unacceptable levels or quickly exhaust the available adsorption capacity of GAC thereby requiring regeneration. A sudden peak of SOC's in the influent to GAC could also cause desorption into the treated water of previously adsorbed SOC's leading to unacceptable levels of these compounds in the finished water. This issue was addressed to some degree through a spiking study conducted on pilot columns at the EEWTP, as discussed in Chapter 10 and Appendix L. However, continued uncertainties with respect to the nature of potential SOC contaminants still exist and are a cause of continued concern.

As mentioned previously, it is believed the process combinations monitored at the EEWTP have sufficient operational flexibility to respond to potential influent spikes of SOC's. However, it was not possible to simulate all possible spill events and, thus, no quantitative assessment can be made on the impact of spills on finished water quality. The appropriate strategy for dealing with unpredictable contamination is to have adequate monitoring of influent water quality and to provide the capabilities for diversion of the raw water or treated water should that be necessary.

### SUMMARY

Several variations in influent water quality are of sufficient importance to warrant consideration in the design of an estuary water treatment plant. Included in the next section are discussions of process combinations or design considerations that address the potential problems caused by TDS, nitrate, and unpredictable contamination by organic compounds.

The process combinations demonstrated at the EEWTP have the flexibility to adequately respond to variations in influent water quality for many of the parameters monitored. Unpredictable increases in the physical/aesthetic, microbiological and metal parameters are not expected to overload the treatment capacities of the processes monitored. This, however, assumes adequate monitoring of influent water quality to allow time for process changes to maintain desired finished water quality.

## SECTION 7

### DESIGN ALTERNATIVES/CONSIDERATIONS NOT MONITORED AT PLANT-SCALE

The cost estimates for a 200 MGD estuary water treatment plant presented in Section 5 were based upon the two main process combinations monitored at the EEWTP. The design criteria used to develop the costs were based upon actual operating conditions. Adsorption on GAC was an integral part of both process combinations. However, the estimated full-scale costs for the GAC process in each process combination were based upon operating conditions at the EEWTP and not upon more realistic full-scale plant design practices. This was done to give an estimate of the cost to produce a finished water quality similar to that which was monitored.

Bench-scale and pilot-plant scale studies were conducted at the EEWTP and combined with computer modeling to better develop more realistic design criteria for full-scale design of the GAC adsorption process. This section discusses the cost implications of more realistic regeneration criteria for GAC adsorption in a full-scale estuary water treatment plant based on the information presented in Chapter 10.

Also discussed in this section are full-scale treatment process combinations required to remove those water quality parameters which might exceed desired levels in the finished waters because of high levels in the estuary. Based upon the results of pilot-scale testing at the EEWTP, process combinations presented include air stripping as an additional barrier for removal of volatile organic chemicals and reverse osmosis to remove TDS, nitrate, sodium and other contaminants, including TOC and TOX.

The last issue discussed in this section is process reliability. Because the estuary is an unprotected source, the operation of an estuary water treatment plant would need to have greater than conventional process reliability in terms of the quality of the finished water produced. Concepts are presented that would result in a more reliable full-scale plant and better accommodate fluctuations in the quality of the influent water quality.

#### GAC DESIGN ALTERNATIVE

Based upon the results from bench-scale and pilot-scale studies and computer simulation of adsorption on GAC, design criteria for a full-scale estuary water treatment plant can be specified that would result in cost savings relative to the cost estimates presented in Section 5. The treated water quality from this GAC process (utilizing parallel contactors and blended effluent regeneration criteria) will not be of identical water quality to that monitored at the EEWTP. However, the water quality can be controlled by the treatment objectives used to indicate when the carbon would need to be regenerated. The design,

Design Alternatives/Considerations  
Not Monitored at Plant-Scale

construction, and operation of a GAC adsorption process based upon the concepts discussed in this section would utilize the benefits of GAC while minimizing costs as much as possible.

#### DESIGN CONSIDERATIONS

The following design factors are recommended for incorporation into the full-scale GAC design:

1. Use of a bituminous based carbon, such as F-400.

As described in Chapter 10 and Appendix I, the F-400 GAC gave the best results of the three carbons studied for both the alum and lime treated waters. The use of the harder bituminous based carbon would also lessen the possibilities of carbon loss due to abrasion during carbon handling and regeneration.

2. Use of parallel contactors.

Operation of the GAC contactors in parallel can substantially decrease the carbon usage due to better utilization of the adsorption capacity of the carbon. The effluents from all of the parallel contactors would be blended to achieve an overall treatment objective (e.g., a TOC concentration of 1.0 mg/L in the treated water). This allows some of the parallel contactors to operate beyond the treatment objective since other contactors are treating the water to levels less than the treatment objective. More of the adsorption capacity of the carbon is therefore used before regeneration is required.

The design of the full-scale GAC contactors would have a two-stage configuration. That is, there would be 31 parallel sets of two contactors in series. This two-stage configuration makes it easier to utilize more of the adsorption capacity before regeneration. When the treatment objective is reached, the lead contactor (in the next set of contactors to be regenerated) would have its carbon replaced with virgin or regenerated carbon, and then be placed back in service as the lag contactor with the original lag contactor now the lead contactor. Such two-stage adsorption is particularly important with respect to efficient utilization of GAC adsorption capacity for SOC's because parallel operation does not ensure complete exhaustion of the carbon. The effectiveness of GAC as a barrier for these compounds is thus improved.

3. Use of fifteen minute EBCT.

The results presented in Chapter 10 and Appendix I illustrate that longer EBCTs can result in lower carbon usage rates. However, when a number of contactors are operated in parallel, cost advantages of longer EBCTs are diminished. This is the case when using the 32 sets of two-stage contactors proposed for use in the full-scale plant. A lower EBCT results in capital cost savings.

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### TREATMENT OBJECTIVE

Carbon usage rates and resulting costs are presented below for two treatment objectives. TOC, a surrogate organic parameter easily monitored, is suggested for use as the parameter controlling the regeneration frequency. Costs are presented for operation of the parallel GAC contactors until TOC treatment objectives of 1.0 and 2.0 mg/L in the blended finished water are exceeded. At that point the contactor that had been in service the longest period of time would have its carbon regenerated.

The selection of the TOC treatment objective is somewhat arbitrary. TOC is a surrogate parameter and mainly represents naturally occurring organic matter, principally humic substances. It has been shown at the EEWTP, however, that TOC will generally break through the contactor before other organic compounds of potential health concern. In addition, tests showed that TOX began to pass through the GAC in a similar pattern to TOC. The relative safety of the water with respect to levels of trace organics can thus be controlled to some extent by selecting the TOC requirement in the treated water at levels where little breakthrough of synthetic organic chemicals is expected to occur.

### WATER QUALITY IMPLICATIONS

The water quality produced in a full-scale plant using the design concepts presented above would not be the same as that monitored at the EEWTP. During Phases IA and IB the GAC contactors were allowed to operate until the effluent TOC concentration consistently exceeded 2.0 mg/L. After eight months of operation in Phase IIA, the GAC contactor effluent TOC concentration was approximately 1.5 mg/L. If parallel operation was used in the full-scale plant with a TOC treatment objective of 2.0 mg/L, the water quality from the full-scale plant could be assumed to be roughly similar to that monitored at the EEWTP during the final stages of operation of the single GAC contactor. If the treatment objective were 1.0 mg/L, then the water quality from the full-scale plant could be approximated by that produced at the EEWTP sometime in the middle of the GAC run.

It is difficult to predict the water quality anticipated from a full-scale plant using parallel contactors. There would probably be a somewhat higher concentration of some organic compounds due to the fact that some of the parallel contactors would be operating at a level beyond the TOC treatment objective. The overall water quality cannot be estimated, however, because of the multi-component nature of the organics in the water and the competitive interactions of these compounds during adsorption.

The blending of the effluent from the parallel contactors should not present a water quality problem in the full-scale estuary water treatment plant. If adequate monitoring of the effluent for various organics of concern is provided, the use of parallel contactors is expected to provide effective treatment of the water while minimizing GAC costs.

**Design Alternatives/Considerations  
Not Monitored at Plant-Scale**

**DESIGN CRITERIA**

For comparison with the GAC process costs presented in Section 5, cost estimates were generated based upon the design considerations discussed above. A fifteen minute EBCT is used with the carbon usage rates shown in Table 11.7-1. These usage rates were developed based upon bench-scale, pilot-plant scale and modeling studies.

**TABLE 11.7-1  
PARALLEL CONTACTOR CARBON USAGE RATES**

<u>TOC Treatment Objective, mg/L</u>	<u>Carbon Usage Rate g/m<sup>3</sup> (lbs/MG)</u>	
	<u>Phase IA</u>	<u>Phase IIA</u>
1.0	18 (150)	25 (210)
2.0	7 (60)	13 (110)

For comparison, the carbon usage rates in the cost estimate in Section 5 for Phase IA and IIA were 250 lbs/MG and 350 lbs/MG, respectively.

**FULL-SCALE GAC COSTS**

Shown in Table 11.7-2 are estimated costs for the full-scale process. These costs are based upon the design considerations discussed in this section. Costs are included for TOC treatment objectives (T.O.) of 1.0 and 2.0 mg/L. For comparison, the GAC costs developed in Section 5 for the process combinations as operated at the EEWTP are also shown. All costs are as of April 1983 and include all costs associated with using GAC, including regeneration facilities.

As is seen, substantial cost savings can be realized using the design considerations discussed in this section. The major savings in construction costs in Phase IIA is in reducing the EBCT from thirty to fifteen minutes. The parallel contactor operation scheme allows for this without resulting in a substantial increase in carbon usage rates. The lower GAC usage rates require smaller regeneration facilities and significantly reduce operating costs. These cost estimates indicate however, that GAC process costs are still high relative to the other treatment processes in the proposed process combinations for the estuary water treatment plant.

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Not Monitored at Plant-Scale

Table 11.7-2

**ESTIMATED FULL-SCALE GAC PROCESS COSTS**  
(April 1983)

	Capital Costs (\$ Million)	Annual O & M Costs (\$ Million)	Cost in Cents/1,000 Gal <sup>a</sup> (\$/1,000 m <sup>3</sup> )
Phase IA (as operated)	36.1	5.2	15.3 (40.5)
Phase IA (TO=1.0 mg/L)	35.3	3.8	13.2 (34.9)
Phase IA (TO=2.0 mg/L)	33.5	2.3	10.8 (28.6)
Phase IIA (as operated)	49.4	7.0	21.4 (56.5)
Phase IIA (TO=1.0 mg/L)	36.1	4.6	14.5 (38.4)
Phase IIA (TO=2.0 mg/L)	34.7	3.1	12.1 (32.0)

a. Includes costs for sitework, contractor overhead and profit, legal, fiscal, and administrative, interest during construction, and contingency. These costs are not included in the capital costs shown.

**ADDITIONAL BARRIER FOR ORGANICS**

As discussed in Section 6, one concern regarding operation of an estuary treatment plant is the response of processes to sudden increases in influent levels of synthetic organic chemicals. Spills in the estuary or sewer system tributary to the Blue Plains Wastewater Plant can result in high concentrations of SOC's in the plant influent. Spill occurrences, similar to those experienced on major river systems in the U.S. and elsewhere, could occur such that the level of SOC's might exceed the ability of the GAC process to remove them to acceptable levels. A conservative process combination would include several treatment barriers to prevent these organics from reaching the consumer. An additional organics barrier could also prevent either the rapid exhaustion of the GAC or the desorption of already adsorbed organics from the GAC into the finished water.

As discussed in Chapter 10, pilot scale studies at the EEWTP demonstrated that packed tower air stripping effectively removes volatile organic chemicals (VOC's). Air stripping would provide an effective barrier against all six of the VOC's currently being considered for regulation (see Chapters 1 and 9). The costs for air stripping also appear reasonable when compared with other methods of VOC removal especially GAC. Based on these considerations, a full-scale treatment process combination which includes packed tower air stripping was considered and is discussed below.



**Design Alternatives/Considerations  
Not Monitored at Plant-Scale**

**PROCESS DESCRIPTION**

Packed tower air stripping would be included in the process combination evaluated in Phase IA operation of the EEWTP. The full-scale process combination would consist of the following:

- Alum/Polymer Coagulation
- Gravity Sedimentation
- Intermediate Chlorination
- Gravity Filtration
- Packed Tower Air Stripping
- GAC Adsorption
- Final Chlorination

One advantage of packed tower air stripping is its operational flexibility to start-up on short notice, with minimal difficulty associated with long periods of shut-down. It, therefore, could be bypassed except during periods when there were sufficient levels of VOCs in the influent to warrant its use.

Air stripping is not intended to replace GAC as the main barrier to organics contamination since air stripping would not remove non-volatile SOC's. When operated, it would remove VOCs and reduce the loading on the GAC thereby potentially prolonging the time between GAC regeneration.

**WATER QUALITY IMPLICATIONS**

By providing an additional barrier for removal of some of the SOC's that might occur in the estuary because of a spill, air stripping makes the process combination more reliable. Air stripping would also remove organic compounds from the water prior to GAC adsorption and thereby minimize or prevent a SOC spike from desorbing previously adsorbed compounds on the GAC into the treated water.

**ESTIMATED COSTS**

Packed tower air stripping costs are estimated based upon design criteria developed during pilot-plant scale testing at the EEWTP. Both capital and operating costs are presented. It is likely, however, that the operating costs for air stripping are not completely additive to the operating costs of the alum/GAC/chlorine process combination. As discussed, the air stripping process need not operate all the time. When in operation, it would reduce the organic loading onto the GAC and thereby reduce GAC process operating costs. As a conservative estimate, the operating and maintenance costs will be included with the capital costs in generating a unit cost of water treated.

The capital costs for a packed tower air stripping process in a 200 MGD estuary water treatment plant would be 11.9 million dollars. The annual O&M costs would be 0.8 million dollars a year. The costs for air stripping in terms of cost per volume of water treated would be 2.8 cents/1000 gal. All costs are as of April 1983. The basis for design was presented in Chapter 10.

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REVERSE OSMOSIS

Concern was expressed in Section 6 that TDS and nitrate levels in the estuary could exceed target water quality goals in the finished water. Most of this concern was based upon uncertainties as to what the TDS and nitrate concentrations would be in the future at Chain Bridge under drought conditions. The process combinations monitored at the EEWTP did not remove these dissolved salts. As mentioned in Chapter 9, there is also possible concern for sodium. Sodium was frequently present in the EEWTP finished water in concentrations exceeding the optimum range recommended by EPA.

The reverse osmosis (RO) process was studied in a 7 gpm sidestream process. As discussed in Chapter 10, the process consistently removed more than 97 percent of the TDS and more than 90 percent of the nitrate. The hollow fiber polyamide membranes used also demonstrated approximately 90 percent removal of sodium.

EEWTP studies also showed that RO could remove 80 percent of the TOC, 95 percent of the TOX, and approximately 50 percent of the THMs. Based upon these results it was judged appropriate to include RO in a treatment process combination for a full-scale estuary water treatment plant. The main advantage of RO is that it would be able to remove TDS, nitrate and sodium. RO also removes organic compounds and may be used in place of GAC, although more extensive monitoring of the RO process is needed to confirm organics removals for the many compounds monitored at the EEWTP. The main disadvantage would be its cost.

PROCESS DESCRIPTION

The process combination that would include reverse osmosis would consist of the following processes:

- Alum/Polymer Coagulation
- Gravity Sedimentation
- Intermediate Chlorination
- Gravity Filtration
- Reverse Osmosis
- Final Chlorination

Because of the high expense of the RO process, it would not be practical to treat all 200 MGD of the water through the RO process. Based upon the removals necessary to produce a satisfactory water quality, the RO process was sized to treat 100 MGD of water and to blend this with water that bypassed the RO process. A satisfactory water quality was defined as having a nitrate concentration less than 5 mg/L (as N), a sodium concentration below 20 mg/L, and TDS levels less than 500 mg/L. Assuming an 85 percent recovery of product water, the RO process would have a capacity of 118 MGD. Because of the modular construction of the RO process, it is possible that less than one-

## **Design Alternatives/Considerations Not Monitored at Plant-Scale**

half of the 200 MGD capacity of the full-scale estuary water treatment plant would have to be treated by the RO process during periods of improved influent water quality.

### **WATER QUALITY IMPLICATIONS**

As discussed, the reverse osmosis process would effectively remove TDS, nitrate, and sodium. Limited EEWTP studies indicated that TOC and TOX could also be effectively removed. However, there were indications that some of the smaller SOC molecules, particularly VOCs, might not be effectively removed. More extensive studies should be conducted prior to the design and construction of a full-scale estuary water treatment plant to ensure that all possible water quality concerns would be adequately addressed by this process combination. It is likely, though, that the RO process could replace the GAC and still produce water acceptable for human consumption. Another possible process combination deserving potential future consideration would be RO in combination with air stripping. Although not specifically discussed, costs may be inferred from discussions for the separate processes. A process combination using RO is obviously superior to the other process combinations discussed in removing TDS, nitrate, and sodium.

### **ESTIMATED COSTS**

Estimated capital costs for an 118 MGD reverse osmosis process would be 102.3 million dollars. All costs are as of April 1983. Annual operation and maintenance costs would be 26.3 million dollars. Assuming the RO treated water is blended with water that has by-passed the RO process to produce 200 MGD of finished water, the reverse osmosis process would cost 50.3 cents/1,000 gallons of finished water. (The actual cost for treating 1,000 gallons is twice as high but blending the RO treated water with bypassed water reduces the unit price of finished water produced.) These costs reflect the difficulty in removing TDS, nitrate, and sodium. The RO costs are based on the use of either spiral-wound or hollow fiber membranes. A three year membrane life was assumed in the cost estimates. Costs for brine disposal are not included.

### **POTENTIAL PROCESS PROBLEM**

A potential problem with the RO process is the disposal of the brine solution that is rejected by the membrane. This brine solution contains all the impurities removed by the RO process. The disposal of 18 MGD of this brine could be a problem if the brine could not be discharged into the estuary. The impact of this brine injection into the estuary under drought conditions would have to be investigated if the RO process were used in an estuary water treatment plant.

### **PROCESS RELIABILITY**

A principal in treating a contaminated raw water source is process reliability. The treatment process combination must produce water of acceptable quality

## Design Alternatives/Considerations Not Monitored at Plant-Scale

continuously. There are three major areas of concern: 1) dealing with unpredictable contamination (spills); 2) adequate control of process performance; and 3) providing for mechanical reliability.

As previously discussed, spills are a definite possibility in the Potomac estuary. It is possible to include sufficient types of processes in an estuary water treatment plant to properly respond to any spill event, but this could be prohibitively expensive. It is necessary to have sufficient monitoring of the influent water quality to be able to make process adjustments to respond to spikes of various parameters in the plant influent. If sufficient monitoring were conducted and if the facilities were available, it could be possible to bypass either the influent water or the water at various stages in the treatment process back to the estuary. This might result in a period where treated water was not being produced, but it would prevent water of unsatisfactory quality from entering the distribution system. This bypass option could also serve to protect a process such as GAC from excess organic loading that could adversely affect its operation once the spike had passed. As opposed to wastewater treatment where the wastewater should always be adequately treated prior to discharge into the environment, water treatment operation can totally cease for a short period of time provided that finished water storage capacity is available. The key issues are the ability to adequately monitor the influent water source and the capability to respond to adverse influent water quality.

These same key issues are relevant in having adequate control of process performance. There must be adequate monitoring and there must be sufficient time to adequately respond to any process upsets. The means must also exist to make process adjustments easily to respond to changing situations.

As discussed, a mechanical reliability analysis is an important component in the proper design of water treatment plants. Redundant equipment is provided to prevent treatment downtime or the adverse impact of malfunctioning equipment.

### DESIGN CONSIDERATIONS

The key design considerations that should be included in the full-scale estuary water treatment plant to provide for better process and mechanical reliability are the following:

1. Provide for a raw water reservoir.
2. Provide for adequate raw water monitoring.
3. Provide for adequate monitoring of water quality in the treated water.
4. Provide for redundant instrumentation.
5. Provide for treated water diversion.

Ideally, a raw water reservoir treating water from a contaminated source like the Potomac estuary would have a detention time of up to one day. This would provide time to monitor the quality of the influent water and decide if the water were unsuitable for treatment. Considering the fact that land acquisition could be a financial problem or the fact that underground storage would be very

## Design Alternatives/Considerations Not Monitored at Plant-Scale

expensive, the size of the raw water reservoir would probably be limited by cost considerations. The minimum size of the raw water reservoir should be for a two to four hour detention time. This would at least provide for some advance monitoring of water quality to decide if severe variations in water quality had occurred. Provision should exist to return the water in the raw water reservoir back to the estuary in a location where it would not likely appear again in the raw water intake.

It is desirable to monitor water quality on a real-time basis. If for any reason the raw water quality or treated water quality should deteriorate, the water can be diverted to waste. The need exists for continuous water quality monitoring of the influent raw water, the treated water of various processes, and the finished water. The NASA study at the Santa Clara Valley Water District Water Reclamation Facility (Brooks, et al., 1981) demonstrated the usefulness and reliability of a number of automatic analyzers and detectors. These should be considered at a full-scale estuary water treatment plant as a means of providing water quality information quickly enough to allow for appropriate process decisions to be made.

Any instrumentation used for monitoring water quality would need to have sufficient backup to preclude problems caused by equipment outages or malfunctioning. Again, the concept of fault tree analysis coupled with the estimated probabilities for various types of equipment failure could lead to the design of a more reliable monitoring system.

As mentioned before, there should be suitable piping, valving, and in some cases pumping, to provide for discarding water at several points throughout the treatment plant. This would give needed flexibility in assuring the quality of the finished water.

### COST IMPLICATIONS OF RELIABILITY ISSUES

Providing for the reliability design considerations discussed would obviously increase the cost of the full-scale plant. However, because of the nature of the raw water source, the investment would be recommended if the plant were ever constructed. Between now and the time the full-scale plant might be constructed, there will undoubtedly be advances in water quality monitoring systems. A complete study of available water quality monitoring systems should be made if and when a full-scale plant is ever designed.

A raw water reservoir with several hours detention time will have a capital cost of anywhere from two to eight million dollars depending upon the nature of the reservoir. Water quality monitoring systems, with adequate backups, would have a capital cost in the range of one to three million dollars, depending upon the level of sophistication and control. Providing adequate piping and valving for diverting flows back to the estuary would have capital costs in the range of one to two million dollars. All costs are as of April 1983.

The return on the investment of the above capital costs would be a more reliable estuary water treatment plant. Considering the unprotected nature of the Potomac estuary, the benefits appear to exceed the costs.

## SECTION 8

### SUMMARY

The purpose of this chapter was to present costs for a 200 MGD estuary water treatment plant. Costs were presented for the two main process combinations monitored at the EEWTP. The design criteria used for the cost estimates were based upon the operating conditions at the EEWTP.

The implications of varying influent water quality were discussed and several potential problem parameters and conditions were noted. Two other process combinations that included processes that were only evaluated at pilot-scale at the EEWTP (air stripping and reverse osmosis) were considered for full-scale plant design. These process combinations were able to address the problem parameter/conditions noted.

Also, because of the importance of GAC to the process combinations monitored and because of the relatively high costs associated with the GAC process, other GAC design alternatives were considered for the full-scale plant. More realistic design criteria (use of parallel contactors, bituminous based GAC, and fifteen minute EBCT) resulted in a decrease in the GAC process cost estimates.

Table 11.8-1 summarizes the pertinent information concerning various treatment process combinations considered for full-scale plant design. As is seen, there is a trade-off between water quality and cost. If and when an estuary water treatment plant is ever designed and constructed, further consideration will have to be given to these trade-offs.

As shown in Table 11.8-1, the estimated unit costs for water treated at an estuary water treatment plant based upon the process combinations demonstrated at the EEWTP are significantly higher than the unit costs at a conventional water treatment plant. The activated carbon adsorption process constitutes a major portion of this increase in cost. A main purpose of the GAC is to provide a barrier to synthetic organic chemicals in the plant influent water.

The concern for reliability in producing a finished water of acceptable quality from a raw water source subject to contamination leads to the multiple-barrier approach. Air-stripping, for example, was discussed in this chapter as one possible additional barrier to volatile SOC's. However, this additional barrier increases treatment costs, as shown in Table 11.8-1. If and when an estuary treatment plant is designed and constructed, consideration will have to be given to the concept of multiple-barriers to parameters of concern. The advantages of greater reliability in acceptable finished water quality must be weighed against the increased costs.

TABLE 11.8-1

## PROCESS COMBINATIONS FOR CONSIDERATION

Process Designation	Main Unit Processes	Comment	Water Quality Implications (Relative to Monitored Processes)	Cost Cents/1,000 Gal <sup>a</sup> (\$/1,000 m <sup>3</sup> )
IA (No GAC)	Alum+Cl <sub>2</sub> +Filt+Cl <sub>2</sub>	Conventional Water Treatment Process	Decreased removal of organics. No barriers to SOC <sub>s</sub>	19.0 (50.5)
IA	Alum+Cl <sub>2</sub> +Filt+GAC+Cl <sub>2</sub>	As operated at EEWTP	As monitored in Phase IA	34.3 (90.7)
IIA	Lime+Filt+GAC+O <sub>3</sub> + (Cl <sub>2</sub> +NH <sub>3</sub> )	As operated at EEWTP	As monitored in Phase IIA	47.6 (125.8)
IA with revised regeneration criteria and more optimum design	Same as IA	Regenerate carbon as required to maintain blended effluent at: a. 1.0 mg/L TOC b. 2.0 mg/L TOC	Similar to IA at end of GAC run. Higher concentration of organics.	a. 32.2 (85.0) b. 29.8 (78.7)
IIA with revised regeneration criteria and more optimum design	Same as IIA	Regenerate carbon as required to maintain blended effluent at: a. 1.0 mg/L TOC b. 2.0 mg/L TOC	Similar to IIA at end of GAC run. Higher concentration of organics.	a. 40.7 (107.5) b. 38.3 (101.1)
IA with air stripping	Same as IA with air stripping prior to GAC	Air stripping tested at pilot-scale at EEWTP	Additional barrier to VOC <sub>s</sub>	37.1 (98.1)
IA (no GAC) with reverse osmosis	Alum+Cl <sub>2</sub> +Filt+RO+Cl <sub>2</sub>	RO tested at pilot-scale at EEWTP	TDS, NO <sub>3</sub> , and Na removal. Modified removal of SOC <sub>s</sub>	69.3 (183.9)

<sup>a</sup>. Costs as of April 1983.

Summary

## REFERENCES

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